12-1-2010

The influence of auditory cues on visual spatial perception

Joseph W. Geeseman
Southern Illinois University Carbondale, jgoose@siu.edu

THE INFLUENCE OF AUDITORY CUES ON VISUAL SPATIAL PERCEPTION

by

Joseph W. Geeseman
B.A., Southern Illinois University, 2005

A Thesis
Submitted in Partial Fulfillment of the Requirements for the
Master of Arts, Brain and Cognitive Sciences

Department of Psychology
in the Graduate School
Southern Illinois University Carbondale
August 2010

THESIS APPROVAL

THE INFLUENCE OF AUDITORY CUES ON VISUAL SPATIAL PERCEPTION

By

Joseph W. Geeseman

A Thesis Submitted in Partial

Fulfillment of the Requirements

for the Degree of

Master of Arts

in the field of Brain and Cognitive Sciences

Approved by:

Dr. Matthew Schlesinger, Chair

Dr. Reza Habib

Dr. M. H. Clark

Graduate School
Southern Illinois University Carbondale
April 21, 2010

AN ABSTRACT OF THE THESIS OF

Joseph W. Geeseman, for the Master of Arts degree in Brain and Cognitive Sciences, presented on April 21, 2010, at Southern Illinois University Carbondale.

TITLE: THE INFLUENCE OF AUDITORY CUES ON VISUAL SPATIAL PERCEPTION

MAJOR PROFESSOR: Dr. Matthew Schlesinger

Traditional psychophysical studies have been primarily unimodal experiments due to the ease in which a single sense can be isolated in a laboratory setting. This study, however, presents participants with auditory and visual stimuli to better understand the interaction of the two senses in visuospatial perception. Visual stimuli, presented as Gaussian distributed blobs, moved laterally across a computer monitor to a central location and “bounced” back to their starting position. During this passage across the screen, a brief auditory “click” was presented via headphones. Participants were asked to respond to the bounce of the ball, and response latency was recorded. Response latency to the bounce position varied as a function of baseline (no sound) and the varying sound offset locations.

ACKNOWLEDGMENTS

I would like to thank the Child Development Laboratory of Southern Illinois University for access to equipment used in data collection. I am indebted to my graduate advisor, Dr. Matthew Schlesinger, without whom this project would not have been possible. I would like to thank Dr. Reza Habib and Dr. M. H. Clark for their advisement during the development of this project. I have many thanks for Dr. Michael Young for his hallway advice and impromptu questions that kept me on my toes and constantly looking deeper into my project. I would also like to thank Joshua Chin, Eric Greenlee, Jillian Mayer, and Katrina Bowen for assistance in running the experiments.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Attributing an individual sensory experience to an individual object is quite easy; the smell of a flower, the sound of a song on a radio, the taste of candy, and so on. Many experiences, however, require assessing information from two or more senses at any given time. For example, watching for traffic and listening to car horns when crossing an intersection of a street or participating in a wine tasting. How do multiple sensory cues from an object manifest as an individual experience instead of multiple individual experiences? The perceptual experience of our everyday lives is produced by the integration or competition of our sensory systems. Often what we perceive is the result of a blending of two or more senses (Alsius, Navarra, & Soto-Faraco, 2007; Arnott, 2005; Heron, Whitaker, & McGraw, 2004; Fujisaki & Nishida, 2006; Mann, 2007; McGurk & MacDonald, 1976; Sanabria, Luplanez, & Spence, 2006; Sekuler, Sekuler, Lau, 1997; Shams, Kamitami, & Shimojo, 2002; Watanabe, 2001).

Perhaps the most common crossmodal experience is flavor perception where the odor and taste of our food combine to produce the flavors we perceive (Mann, 2007). A disruption in either taste or smell can impair or eliminate flavor discrimination abilities. Speech perception is also an example of a common multisensory experience. When one can see the lips of a speaker while processing the auditory aspects of speech, the perceiver can better understand the speaker (Erber, 1975).

An example of multisensory integration that is pertinent to students is if we are performing a demanding task in one modality, we may lose our perceptual abilities in other modalities (Alsius et al., 2007). For instance, if you are writing notes in class or at a seminar instead of only listening, what is being said by the lecturer may be less clear. A final example of a multisensory experience is if people see objects colliding with one another (e.g. hands clapping, two cars crashing, etc.) a sound often accompanies the impact (Heron et al., 2004; Sekuler et al., 1997). These are all examples of input from one sense integrating or competing with another sense to influence ones' perception of their external world.

There are several instances to be discussed in this paper where information received through one sense can influence what is perceived by another. I am going to begin by defining several key ideas and terms that are often used in the literature on perception, particularly regarding hearing and seeing. After establishing the terms and theories on which this paradigm is based, I will highlight two major theories of crossmodal integration. Finally, I will address how sound has been shown to influence visual perception in prior studies and how I intended to explore audiovisual interactions.

CHAPTER 2

LITERATURE REVIEW

Sensory Interactions

Several methods have been used to investigate the interactions of our senses. This section will introduce some key terms and provide an explanation of the methods that have been used to explore crossmodal interactions. Some interactions described will illustrate everyday experiences, such as the interaction of smell and taste, but others will be less obvious, like olfactory effects on vision.

An everyday experience that involves crossmodal integration that most individuals become aware of during their childhood is that of smell and its effect on taste perception. An example of this could be when a child is asked to eat, perhaps, an unfamiliar vegetable, the child may learn that by plugging their nose the vegetable tastes less bitter. Alternatively, a vintner may take a long smell of a wine prior to tasting to enhance the flavor.

An example of how a deficit in one sense can alter the perceptual experience of a different sense can be addressed with flavor perception. Taste receptors in the tongue are sensitive to the five basic flavors (e.g. sweet, salty, sour, bitter, and umami). The airborne particles of our food and drink that we smell, however, are what allow humans to have such a broad range of flavor experiences. In other words, without the ability to smell, we would not be able to distinguish between coffee and tea or a strawberry and a blueberry, aside from the obvious textural and visual cues that accompany these items. The complete loss of one's ability to smell is known as anosmia. An individual with this condition would lose their ability to detect the flavor of foods. If a person loses their ability to taste food they may ultimately be unable to detect rotten or contaminated foods and can actually lead to depression because of their inability to enjoy the experience of eating (Mann, 2007).

Olfactory effects on taste are commonplace and most of the population is aware of the interaction of the two. There have been studies, however, that demonstrate that smell can influence other perceptual experiences. For example, Kemp and Gilbert (1997) investigated how odor can alter our perception of color. They found that people systematically assign hues to specific odors and that the intensity of the odor is inversely correlated with the lightness of the color. Other studies have shown that the brighter a food is colored, the higher intensity subjects rated the odor of that food (Christensen, 1983).

Not only has smell perception been shown to influence the flavor of food and alter color perception, but olfaction has even been shown to influence how one evaluates their sense of touch. Dematte, Sanabria, and Spence (2007) developed a series of experiments that showed how the pleasantness of an odor can influence the tactile perception of fabric. For example, they found that participants presented with pleasant odors perceived fabric that they were touching as being softer, and when being presented with unpleasant odors, they would rate the same fabric as being rougher.

A clinical example of crossmodal interactions can be found when medical doctors test patients for somatosensory sensation after a stroke. Medical doctors examine somatosensory sensation by touching contralesional areas of patients' bodies while the patients' eyes are closed or the examined area is obscured from vision. Experiments have shown visual feedback of being touched can slightly elicit the sensation of being touched for some patients (Halligan, Marshall, Hunt, & Wade, 1997). This has implications in rehabilitation and posits a number of questions on the neuronal underpinnings of crossmodal interactions.

Audiovisual Interactions

The previous section provided a few examples of crossmodal experiences; however, the primary focus of this thesis is on the interaction between sound and vision. Recent studies have demonstrated several different ways that sound can influence ones' visual experience (Heron et al., 2004; Meyer & Wuerger 2001; Sekuler et al., 1997). Some of the studies show how a new visual percept can be developed with the introduction of sound (Meyer & Wuerger 2001; Sekuler et al., 1997) and others demonstrate how sound influences the visual system when the certainty of a visual stimulus is modified (Heron et al., 2004).

McGurk and MacDonald (1976) examined the effect of incongruent audio and visual stimuli via speech perception. Competition of audition and vision is demonstrated through this study, and how an incorrect percept of our environment can be produced by this competition is shown. In this study, participants were presented with a video of a person saying the syllable "ba" repeatedly. However, the audio stream for the video was dubbed over with the syllable "da". If the participants were presented with only the video with no sound, they perceived the actor's lips as saying "ba", and if they were presented with only the auditory stimulus, they heard the syllable "da". When the participants were presented with the video and audio stimuli combined, they perceived the syllable "ga". The auditory and visual incongruence developed a percept of an entirely new syllable that was not presented to the participants of the study. This phenomenon could be explained by the influence or competition of vision and hearing, which will be addressed shortly.

The influence of and competition between one sense and another has explanations based on several theories. Two terms that need to first be defined, influence and competition, will be used throughout this paper. When one sense influences another, the initial sense interacts with a secondary sense to provide a modified perception of the environment for the perceiver. A specific instance of a modified percept due to one sense influencing another is the production of more detail of a stimulus. To reiterate a previous example, the more clearly a person can smell, the better they can taste, as opposed to someone that has a cold and everything tastes bland. Competition is a specific case of sensory influence. For instance, when senses compete with one another, one sense loses weight while the other gains weight in the perception of a stimulus. Weight is a term used to describe the amount of perceptual impact a sense has, and will be discussed more thoroughly later. A special occasion of competition between two senses is a winner-takes-all situation which occurs when one sense may provide all the perceived sensory information for a stimulus, or obtains all of the weight. An example of a winner-takes-all situation during localization could be seen when the perception of speech sounds appears to come from an actor's mouth on a movie theater screen. The auditory signal of an actor's speech never comes directly from the location on the screen that the actor appears, but rather through the speakers located along the walls to the side of the screen (Battaglia, Jacobs, & Aslin, 2003). To explain these ideas, a review of the theoretical claims will be detailed.

First of all, several models have been designed to explain the interaction, integration, and facilitation effects between two or more sensory modalities. The standard theory of multisensory integration suggests that information about our surroundings is a result of neural activation from the combination of information from our sensory organs (Pouget, Deneve, & Duhamel, 2002). A specific example of this theory would be the localization of an object which often occurs from the visual information of an object integrating with the information obtained from the auditory system.

The standard theory of multisensory integration is the theory that is often used in textbooks on perception (Pouget et al., 2002). This theory of perception explains the end result of multisensory integration; however, there are other theories that explain the process of integration. The visual capture theory and the maximum-likelihood theory are two modern theories that explain the underlying processes behind multisensory integration. Visual capture theory, a specific case of winner-takes-all, suggests when vision is the source with the least amount of variance, all of the sensory information is obtained by the visual system (Battaglia et al, 2003). In other words, visual capture theory posits that under certain circumstances vision competes and wins the sum of the possible weight from other senses. Visual capture may be an explanation of a periodic perceptual event that occurs intermittently throughout the day. For example, if a fly were to be buzzing about a room in your home, you may rely completely on the sound of the wings until you gain sight, at which point you may switch to visually tracking the critter until you lose sight, and so on. An important point is that the reliability of your senses varies depending on where you are or the time of day.

Visual capture theory uses the terms reliable and perceptual errors to help explain the processes of multisensory integration. If a system is considered to be more reliable than another, then the more reliable system provides more acute sensory information for the perceiver (Battaglia et al., 2003). For example, during the day, a person with normal vision may rely on their visual system to maneuver in their environment. They would use this system rather than their auditory system because their visual system is more reliable than their auditory system. Empirical evidence of the reliability of these two systems will be addressed later. A perceptual error occurs when a person incorrectly identifies an object, sound, taste, odor, or tactile experience. In other words, if a person were to be presented with a lemon scented solution and they identified the odor as vanilla, their olfactory system would have made a perceptual error.

The visual capture theory may explain how visual sensory information competes for dominance in many situations, but in some situations, people experience information from several sensory modalities at any given time where information from the separate modalities is important. When speaking to another person, the sound of their voice combined with the motion of their lips helps one to recognize words or when localizing an object a person may rely on visual search combined with the sound the object may make (Pouget et al., 2002). A different theory that could explain how information is integrated that does not eliminate the benefit of one sense influencing another is the maximum-likelihood estimation (MLE) theory of sensory integration (Battaglia et al., 2003). MLE theory is going to be explained in the context of auditory and visual interactions, but not explicitly investigated in this thesis.

The maximum-likelihood estimation (MLE) theory proposes that perceptual judgments are made from the weighing of sensory signals based on the relative reliability of the sensory signals in proportion to one another (Battaglia et al., 2003). Weight can be defined as the amount of influence that a particular system has when perceiving a specific stimulus. Therefore, according to MLE, sensory information is combined from separate modalities to produce a perception of one's environment. At any given moment, the veridical properties of a stimulus can modulate the sensory input from a sensory organ(s) and more weight will be provided to the more reliable sense according to this model. For example, if weight is assigned to a sense on a scale of zero to one, we can address the daytime reliance of the visual system explained earlier (Battaglia et al., 2003). The MLE theory would suggest that the visual system may be assigned a hypothetical weight of 0.8 and the auditory system would receive a weight of 0.2 when the perceiver is maneuvering around their environment. This suggests that the visual system would be relied on more than the auditory system, but the auditory system is still influential. The visual-capture theory, however, could also be a special instance of the maximum-likelihood estimation theory. If this is the case, the visual system would receive a weight of one and the other competing senses would receive a weight of zero. With this rationale, auditory information would not have any influence in this environment navigating scenario.

The study done by McGurk and MacDonald (1976) described earlier showed how mismatch between auditory and visual stimuli can produce a percept that is not necessarily a blending of the two stimuli. This situation could be explained by MLE, where there is not equal weight assigned to both auditory and visual signals. To review, the visual stimulus of a person's lips saying “ba” and the auditory stimulus of “da”, produced a percept of “ga” (McGurk & McDonald, 1976). If their findings are to be explained by the MLE model, the explanation would suggest that much more weight is attributed to the visual system. This could be the circumstance because when the participant looks away from the video, the auditory system produces the correct auditory percept. Only when the participant is looking at the video monitor does a perceptual error occur. If this is true, then there may be an incorrect weight attributed to vision which could elucidate the McGurk effect. MLE produces this new percept as a single perceptual output from the two stimuli. Two separate, correct percepts would be perceived if this was not the case. If less weight were attributed to vision due to an attentional demand on a different sense, could the McGurk effect diminish or vanish entirely?

Alsius et al. (2007) integrated the McGurk effect with a second, parallel task. Participants performed rhythmic patterns of differing degrees of difficulty with their fingers while viewing and listening to stimuli like those in the McGurk and MacDonald study. Alsius et al. (2007) found the more difficult rhythmic patterns inhibited the visual influences of the McGurk effect. Specifically, if the tapping exercise increased in difficulty, then the participants more often reported the audible syllable as opposed to the incorrect syllable elicited from the dominance of the visual system. Through this experiment, Alsius et al. (2007) showed that more demanding attentional tasks can influence the weight given to a particular sensory system.

Up to this point, much of the focus of this review has been visuocentric, indicating that the visual system has the largest weight causing the most influence over other sensory systems. Several other studies, however, have established that auditory effects can elicit visual illusory percepts. Meyer and Wuerger (2001) performed a study that revealed how the presentation of sound can influence the visual system to perceive motion when there is, indeed, no directionally congruent motion of the visual stimuli. If a visual stimulus is said to have directionally congruent motion, the stimuli are presented in a manner that can elicit a percept of coherent movement in a specific direction. To be more specific, Meyer and Wuerger (2001) used stereo presented sound to simulate the motion of sound laterally. The visual stimulus was comprised of moving dots on a screen that varied in the amount of directionally congruent motion. When laterally moving sound was presented with randomly moving dots, a percept of visual directional movement was elicited. The induced perception of visual motion can be explained by the weight attributed to each modality by maximum-likelihood estimation theory.

As previously mentioned, the weight of a percept from a given system depends on the reliability of the system due to the veridical properties of the stimuli that are presented. Meyer and Wuerger (2001) modified the visual reliability of their stimuli by manipulating the coherence of the moving dots of the visual stimulus. When sound was presented to the participant, however, it was presented with a constant motion from one speaker to the other. This would give more weight to the auditory stimulus, decreasing the weight attributed to the visual system, and therefore, the illusory percept of visual motion was elicited. To be more specific, the visual stimulus was comprised of randomly moving dots which implies low certainty, but the visual system received a lot of weight due to the reliability of the system. At the moment sound is presented, the auditory system received more weight because there is less variance in the veridical auditory stimulus.

The previous study indicates that sound can induce a visual motion percept, but there are other ways sound can modify visual perception. When visual percepts result from a perceptual error, due to the properties of the stimulus, an illusory visual percept is said to have occurred. In other words, an auditory stimulus presented during a visual event can produce a new or altered visual percept during the event that did not occur, or an illusion. Sekuler et al. (1997) investigated the integration of auditory and visual events that demonstrates the production of an illusory visual percept of a collision based on the temporal presentation of sound. More specifically, the presentation of a brief click during the visual stimulus produced an illusory visual percept. Subjects viewed two discs that moved towards each other, horizontally, on a computer screen. The discs moved continuously through one another and produced a percept of the discs streaming through one another. Some of the trials consisted only of the visual event, but on other trials, during the visual event, a brief click was presented at the point of coincidence, or when the discs were atop one another. When sound is present at or near the point of coincidence, the perception of the two discs bouncing off one another is increased (Sekuler et al., 1997). This study shows that a visual event can be altered to an entirely new phenomenological experience with the presentation of sound.

The Sekuler et al. (1997) study could be explained in a comparable manner as Meyer and Wuerger (2001) with maximum likelihood estimation. When Sekuler et al. (1997) added a brief auditory click to the streaming discs on a computer screen, the weight attributed to the auditory and visual systems changed for an instant. The click was a very punctate, or brief, stimulus, which would allow for weight to be assigned to the auditory system for that short moment. The shifting of higher weight from the visual to the auditory system may explain the new, illusory percept of a collision.

Of particular interest in these studies is the variation of the weight attributed to each sensory system at any given time. One way to experimentally alter the weight attributed to a system is to systematically adjust the relative reliability, which can be modified objectively by a researcher using specific statistical methods. The experimental modification of the stimulus can alter the phenomenological experience, or certainty, for the participants of the stimulus being used. For example, the randomly presented dots Meyer and Wuerger (2001) used in their experiment varied in certainty based on the visually coherent motion of the stimulus.

The standard theory of multisensory integration addressed earlier provides a post hoc definition of the phenomenological experience of the perceiver, whereas this paper is going to address the underlying process that is often explained as a phenomenological experience. The visual capture and MLE approach to multisensory integration are two theories that investigate audiovisual sensory interactions at the process level. In order to better understand the differences of these two approaches to multisensory integration, Heron et al. (2004) will be replicated and discussed.

The motivation for the current study was developed by Heron et al. (2004) due to the experimental manipulations they used to elicit the illusory component of audio-visual integration. They controlled the amount of phenomenological certainty the subjects perceived by experimentally manipulating visual and auditory stimuli. Visual stimuli had variable levels of certainty that was modulated by altering the definition of the borders of the stimuli, and the auditory stimuli varied in duration and temporal location in relation to the visual stimuli to induce discrete levels of certainty (Heron et al., 2004).

The visual stimuli were three blobs that varied in intensity from the center outwards (Heron et al., 2004). The term blob is used to describe the visual stimuli because the center of the stimulus is very bright whereas the further from the center one looks, the more faded the intensity of the stimulus. As a reference for the middle of the screen, two blobs were vertically aligned along the center of the computer screen.

During the experiment, one blob moved from the side of the computer screen towards the center. The two upper and lower blobs defined a central midline, which participants used to identify when the third moving blob aligned with them (Heron et al., 2004). The bounce position of the center blob varied in location laterally about the center and was defined as where the blob changed trajectory and returned to the point at which the trial began (Heron et al., 2004).

The auditory stimuli consisted of short white noise bursts that were described as a brief “click” or a longer “swoosh”. The sound stimulus was presented either synchronous with the visual bounce or 20, 40, 80, or 160 ms prior to the visual bounce position (Heron et al., 2004). The blob’s (visual stimulus) bounce position varied among seven different locations and the auditory stimulus was varied among five temporal locations that were presented coincident or prior to the actual visual bounce position (See Fig. 1). The participants were asked to report whether the blob bounced before or after the midline as defined by the two horizontally placed reference blobs. In addition to reporting the bounce point of the blob, participants were asked to ignore all other cues (Heron et al., 2004).

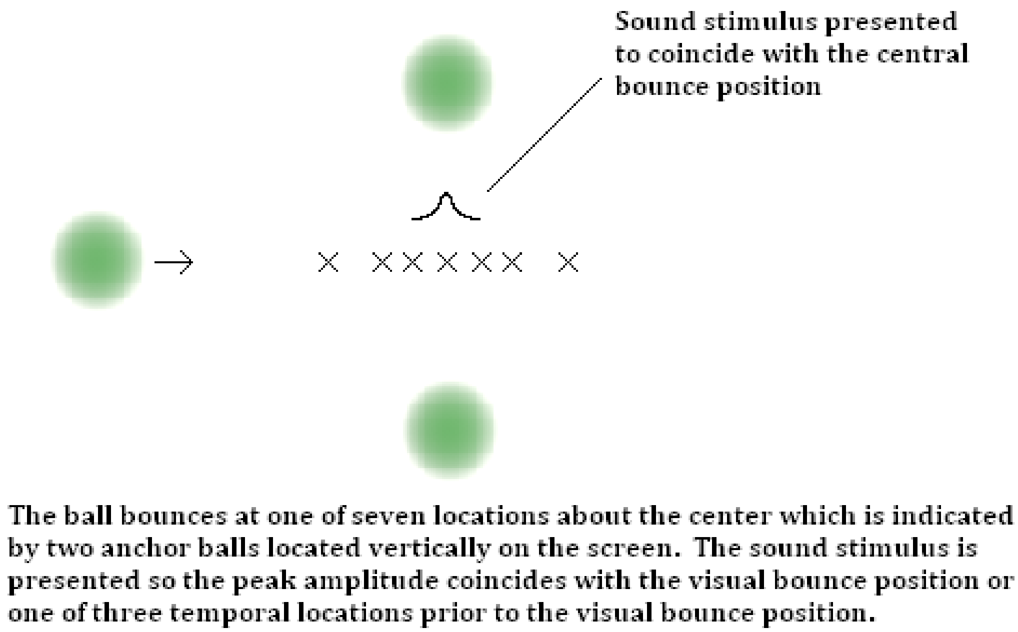

Figure 1. Visual representation of the seven bounce positions for the blobs (visual stimuli) are indicated by crosses. The Gaussian curve is representative of a sound stimulus where the peak amplitude corresponds to the middle bounce position for a trial. It is important to note that participants were to use the center of the blob to identify the bounce position.

Of particular interest are the results of the experiment when the most punctate sound was used. The brief click had differing influence on the perceived bounce position depending on the phenomenological certainty of the blob's spatial position. Heron et al. (2004) found when the blob size is small, which indicates a high level of visual certainty, the presentation of an asynchronous auditory stimulus has little or no effect on the perceived location of the bounce position. As blob size increased (less certainty) and an asynchronous auditory stimulus was presented, however, the perceived bounce position was shifted towards the direction of the auditory stimulus (Heron et al., 2004). In other words, as visual certainty decreased, the influence of sound increased.

Reaction Time

The forced-choice post trial decision of participants from Heron et al. (2004) indicated that participants perceived the visual bounce position as being earlier than the veridical bounce position when visual certainty was low due to the presentation of a brief sound. Some research indicates that when auditory and visual stimuli are presented synchronously, reaction times to the concurrent stimulus are faster and more accurate than if a stimulus in one modality is presented alone (Spence & Driver, 2004). Heron et al. (2004) presented auditory and visual stimuli synchronously and asynchronously, and found the largest effect of sound when the auditory stimulus was presented prior to the visual bounce of the blobs. The method in which participants responded to the stimuli, however, may not have been the most optimal approach to assessing behavior to bimodal stimuli. Post trial responses may have been influenced by post-event cognitive processes. Therefore, in order to more accurately reflect the immediate or online perceptual process, the proposed study will have subjects respond as soon as they see the ball bounce.

Unlike Heron et al. (2004) this study is going to address the online behavior of the participants and is going to use reaction time to measure the behavioral changes due to the varying visual and auditory stimuli. The term *reaction time* will be used loosely to describe the task for this experiment. While it is true that the amount of time between the presentation of the imperative, or response, stimulus and the response of the participants is correctly identified as reaction time, there is a unique circumstance in this experiment that invalidates the use of the term *reaction time*. The situation that renders reaction time incorrect is when participants produce a response prior to the bounce. When this occurs, the response time is negative. Due to the fundamental characteristics of reaction time, the response time cannot be a negative value. Therefore, the term response latency will be used more often to describe the amount of time that passes from the start of a trial to the moment the participants respond.

Heron et al. (2004) indicated that the proportion of before responses increased as the blobs' fuzziness increased when sound was presented prior to the visual bounce. By using response latency as a measure of online behavior, this study reveals that participants may be receiving temporal or additive information about the visual stimulus from the auditory stimulus, thus facilitating shorter response latencies during test trials. An analysis of response latency will reveal the online behavioral changes, mentioned previously, that occur due to the veridical quality of the stimuli instead of a subsequent assessment made by the participants.

A pilot study using similar stimuli as Heron et al. (2004) was conducted to investigate if response latency would vary in a similar manner as the proportion of before responses changed for the original researchers. In this study, participants were presented with visual and auditory stimuli similar to those introduced in Figure 1. Instead of deciding if the ball bounced before or after the midline when the trial was over, as required in the primary study, participants were asked to press a key indicating if the ball bounced before or after the midline as quickly as possible after they perceived the ball to bounce. Some trials had a brief sound presented systematically prior to the veridical visual bounce to examine the effect of bimodal stimulus presentation.

The pilot study indicated shorter response latencies when sound was presented concurrently and prior to a visual bounce stimulus. These findings resulted in a similar behavioral response curve as the perceived bounce position indicated by Heron et al. (2004).

Figure 2 shows the latency data from the pilot study, which have an analogous pattern to the post-trial perceived bounce position data illustrated in Heron et al. (2004). The pilot study data is presented with the horizontal axis specifying the number of milliseconds prior to the visual bounce that sound was presented, and the vertical axis indicates a decrease in response latency due to the presentation of sound (See Fig. 2).

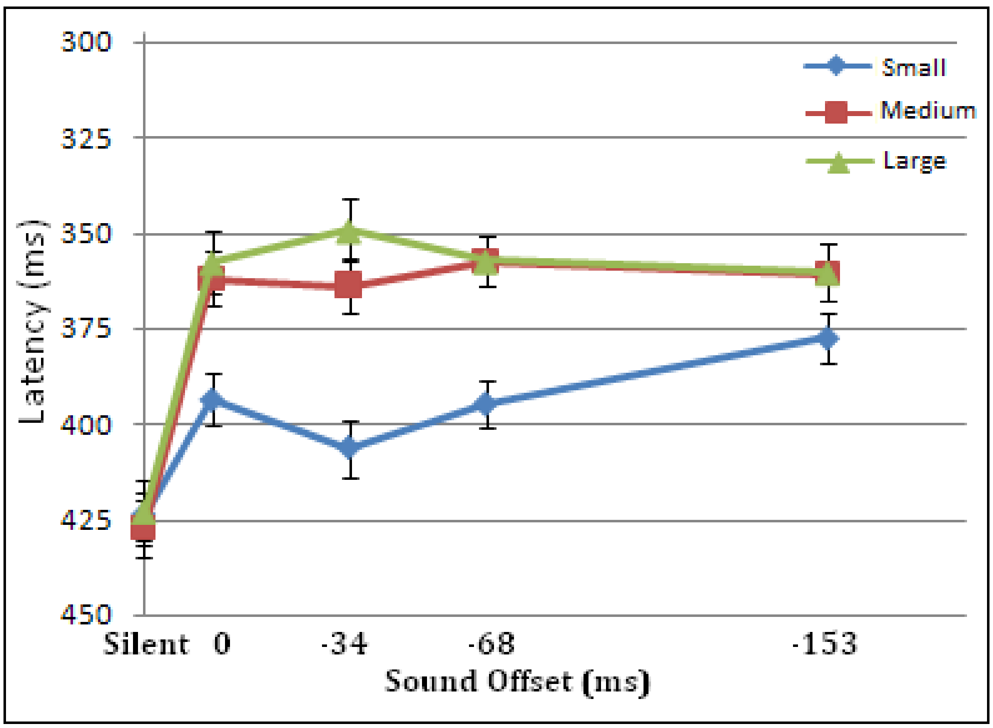

Figure 2. Perceived bounce position as a function of sound offset and ball size as presented in Heron et al. (2004) (left). Pilot study results indicating shortened latency as a function of ball size and sound offset (right).

Recent studies have used stimuli that can facilitate faster response times due to the characteristics of the stimuli, whether unimodal or bimodal or presented synchronously or asynchronously (Barutchu, Crewther, Paolini, & Crewther, 2003; Rolke & Hofmann, 2007). The amount of time between the first stimulus and the second stimulus, in which subjects are to respond, has been posited as a factor in the consequent reaction time to the second stimulus (Los, Knol, & Boers, 1999; Rolke & Hofmann, 2007). These factors, bimodality and temporal precedence, are of particular interest and will be discussed in accordance with the hypotheses for this study.

The task to be studied in this experiment manipulates two stimuli that use hearing and vision in series to generate a response. Some terms used in previous reaction time studies that will be addressed in this paper are warning signal, imperative stimulus, and foreperiod. When using two stimuli, regardless of modality, the first stimulus is called a warning signal that prepares the subject for an impending second stimulus. This warning signal does not necessarily have to provide any information about the second stimulus to decrease reaction times, whether visual, auditory, or crossmodal in nature (Rolke & Hofmann, 2007). The current study does not use what is traditionally considered a warning stimulus in the conventional circumstance that the stimulus is presented prior to the start of the trial. This experiment presents what is referred to as the warning stimulus during the trial, and will systematically vary in temporal relation to the second, or imperative, stimulus.

To reiterate, the first stimulus does not have to be presented synchronously or qualitatively match (i.e., within the same sensory modality) the second stimulus to decrease reaction time. Some researchers believe this is because the first stimulus facilitates reaction time at the premotor processing level (Rolke & Hofmann, 2007). Los et al. (1999), however, suggest that the initial stimulus, or warning signal, provides some temporal information about the second stimulus, or imperative stimulus. The temporal information provided by the warning stimulus could be regarded as a “mental preparedness” to react to the imperative stimulus. The researchers indicated that while the stimuli do not have to share qualitative characteristics, the amount of time between the warning signal and impending stimulus plays a crucial role in reaction time. The period of time between the warning signal and impending stimulus is referred to as the foreperiod. If there is a short foreperiod, subjects tend to have short reaction times to the imperative stimulus. The longer the foreperiod, however, the longer the reaction times are to the imperative stimulus (See Fig. 3).

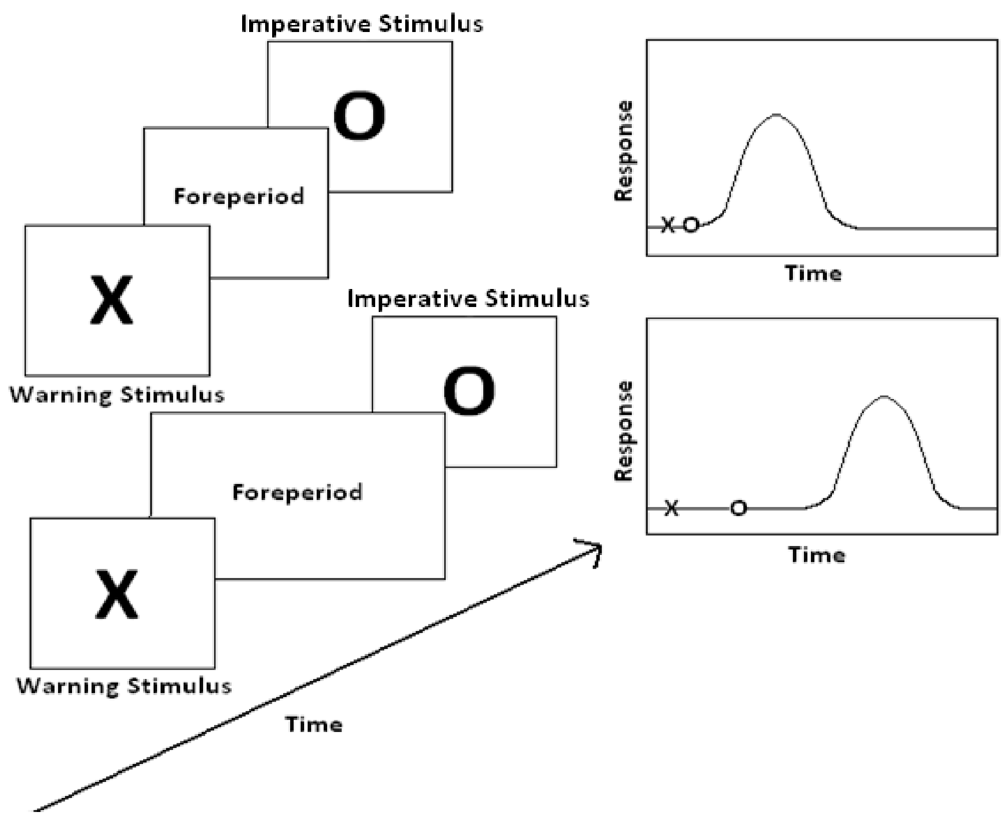

Figure 3. A longer foreperiod, or time between warning stimulus and imperative stimulus, is predictive of slower reaction times to an imperative stimulus than a shorter foreperiod. The distibution curve is a representation of response times as a function of the length of the foreperiod. A short foreperiod elicits faster reaction times (top) and longer foreperiods elicit longer reaction times (bottom).

Following the logic of Los et al. (1999), when a visual stimulus is presented alone, reaction time the stimulus should be slower than when a visual stimulus is presented with synchronous or asynchronous sound. This is posited because the sound stimulus may provide either temporal information, or a “preparedness” to react; or be an additive facilitating factor for a motor response to the imperative visual stimulus. The two scenarios to investigate the effect of the sound stimulus are as follows: First, when the sound is presented prior to the visual bounce, the auditory stimulus performs the role of a warning signal. Second, if sound is presented coincident with the visual stimulus an additive information property can be attributed to the auditory stimulus. Both of these scenarios will result in shorter response latencies to the visual stimulus than if it were presented alone. Also, since the visual bounce is the impending stimulus and the foreperiod between the warning stimulus and impending stimulus is varied, the latencies of the participants should vary in accordance with the varying amount of time allotted to the foreperiod.

CHAPTER 3

HYPOTHESES

The present study will investigate the influence of an auditory stimulus on two dimensions of visual perception. The initial task is to replicate the findings of Heron et al. (2004). Their results indicated that a sound stimulus presented prior to a visual stimulus altered the percept of the veridical properties of the visual stimulus. More specifically, if a sound was presented prior to the "bounce" of the visual stimulus, described earlier, participants perceived the bounce to occur before the event actually happened. An important feature of the current experiment is that the effect of the sound stimulus will be found only in trials where visual uncertainty is high. As previously defined, visual uncertainty is mediated by the fuzziness of the edges of the blobs that will be used as visual stimuli. In this experiment, visual uncertainty is modulated in a similar fashion as Heron et al. (2004). Consequently, predictions regarding the proportion of before responses will correspond to those proposed by Heron et al. (2004).

The proportion of before responses was calculated by dividing the number of before responses by the total number of responses for each trial. Let *R* denote responses, and let *b* and *a* denote before and after, respectively.

$$\textit{Proportion of Before Responses} = \frac{R_b}{R_b + R_a}$$

Accordingly, hypotheses regarding the proportion of before responses are as follows:

1. Relative to the baseline condition, the proportion of trials judged as "before midline bounce" will be significantly higher during the sounded trials.
2. The proportion of before responses for the small blob will be significantly higher than the large blob. The proportion of before responses for the medium blob will fall between the small and large blob. This relationship will maintain at bounce positions prior to and including the midpoint. After the middle bounce position, this relationship will no longer be preserved.
    a. The proportion of before responses for the large blob will be significantly smaller than the small blob at bounce positions closest to the start position and at the midline. The proportion of before responses for the medium blob will be between the small and large blobs. This relationship is hypothesized because there is more spatial certainty for the small blob than the large blob, which will result in more "before" responses at locations prior to the midline.
    b. At bounce positions occurring the farthest from the start position, or after the midline, the proportion of before responses for the large blob will be significantly higher than the small blob. As indicated in #2a, higher spatial certainty for the small blob will result in more "after" responses for locations after the midline, therefore, the proportion of before responses will be smaller for the small blob.
3. The proportion of before responses for the bounce position located the closest distance to the start position will be significantly higher than the proportion of

before responses given for the bounce position located the farthest from the start position.

   a. The proportion of before responses will follow a cubic function across bounce positions.

This study also measured response latency as a second dependent measure to evaluate the effect of sound on visual perception. We believe the effects of the within-trial warning stimulus and the other independent variables will result in a comparable pattern as the proportion of before responses. Therefore, the following hypotheses are posited concerning latency:

4. The presence of sound will significantly reduce latency at bounce at bounce positions prior to and including the middle bounce position.
   a. The facilitative effect of sound will be lost at bounce positions occurring after the midline. This is due to the increase in visual information that occurs from the blob crossing the midline. Once the blob crosses the midline, enough visual information is provided to the participant to make an "after" decision and auditory cues will be minimally utilized under these circumstances.
5. Latency will be larger in the more ambiguous blob bounce positions than in the more salient positions. The ambiguity of the middle bounce positions can be inferred from the proportion of before responses analyzed in the pilot study detailed previously.

a. Latency of responses for the small and medium blobs will be larger in the middle bounce positions than the large blob. The influence of sound on the large blob, or the stimulus with the least visual certainty, will result in shorter latencies than for the blobs with more visual certainty.

Following the logic of the previous hypotheses, a final exploratory independent variable was added to this experiment. If sound presented prior to the bounce of the visual stimulus results in shorter latency than during silent trials, what would happen if sound is presented immediately *after* the visual bounce? This idea led to the following hypothesis:

6. When sound is presented after the visual bounce, latency will be longer than during trials with sound presented prior to the visual bounce.

CHAPTER 4

METHODS

Participants

A sample size of 92 participants was acquired for this experiment. Participants were recruited from an Introduction to Psychology course (PSYC 102) and given course credit for their participation. Normal or corrected to normal vision and normal hearing were required to participate in this experiment. Participants were given an explanation of the properties of the stimuli, but were told to disregard the varying sizes of the visual stimuli and to ignore any auditory stimuli. Consent forms were signed by all of the participants in accordance to the Human Subjects Committee of Southern Illinois University of Carbondale.

Materials

The visual stimuli consisted of three Gaussian blobs that ranged from a rapid decay in intensity to a slow decay as indicated in Figure 4. The distribution from small to large

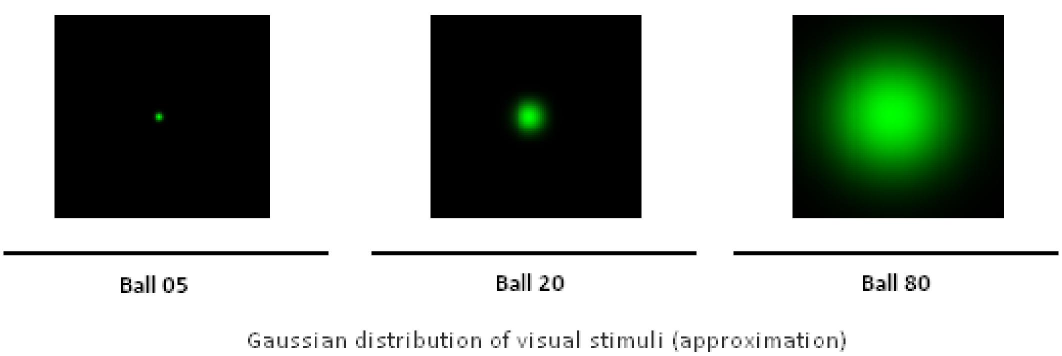

Figure 4. Gaussian distribution of visual stimuli. Numbers represent the decay rate of the stimulus, or σ_v.

provided three explicit spatial boundaries for the visual stimuli. The mathematical description of the luminance-defined Gaussian blobs is

$$L_{mean} + A * \exp(-(d^2)/2\sigma_v^2)$$

where L_{mean} is the mean luminance of the background, A is the luminance amplitude and σ_v is the standard deviation of the Gaussian envelope. The radial distance from the center of the Gaussian is denoted by d (Heron et al., 2004). We used the same three values for σ_v as Heron et al. (2004): 0.05°, 0.20°, and 0.80°.

The auditory stimulus was white noise presented in 17 ms durations through Radio Shack model #33-1225 headphones with the volume set to the same amplitude level for all participants.

The 17 ms noise burst coincided with the frame rate used in this experiment. Frame rate is the frequency that separate images were presented to the participants to induce the perception of motion across the screen. The frame rate used in this experiment was 17 ms/frame ≈ 59 frames/second.

The experiment was presented with 1024 x 768 screen resolution, where one degree of visual angle is equal to approximately 25.5 pixels. The blobs moved at a rate of three pixels per frame or 177 pixels/second. This equates to a velocity of 6.94 visual angle degrees/second (3 pixels/frame @59fps = 177 pixels/sec ≈ 6.94 deg/sec). This velocity was held constant for all blob sizes and was attributed to the speed at which the center of each blob traversed the screen.

Procedure

The experiment consisted of six parts; a visual discrimination task, an auditory test, one set of thirty familiarization trials, and three blocks of 152 test trials (See Table 1). The visual discrimination task was used to assess the participants' ability to distinguish the different locations that the visual stimuli could 'bounce'. The participants were presented with static displays of the visual stimuli. All of the displays included two anchor blobs situated vertically in the middle of the screen and a third blob placed at one of the seven middle locations described previously. Their task was to indicate whether the third blob was to the left or right of the midline.

The function of the auditory test was to evaluate the participants' capacity to hear the auditory stimulus. The participants were presented with a crosshair in the middle of the screen at the start of each of the ten trials. Seven of the trials had the auditory stimulus that was used in the experiment presented during the trials and the other three test trials remained silent. The participants were instructed to press the 'SPACE BAR' if they heard the auditory stimulus during the trial, and to do nothing if no sound was presented. After each sounded trial, they were presented with their reaction time to the auditory stimulus. This was used as feedback for the participants and to reiterate that responses during the experiment were to be as quick and accurate as they could manage. A 100% correct response rate was required to participate in the experiment.

The first set of trials consisted of familiarization trials to expose the participants to the task that they were to perform during the experiment. This also provided an opportunity for lab assistants to assist participants in instructing them to perform the task correctly. The familiarization phase consisted of thirty randomly selected trials from the 456 possible trials indicated in Table 1.

Individual trials consisted of a blob that moved from one side of the screen, toward the center, and then back to its original position. On each trial, two additional stationary blobs were located along the vertical midline of the screen, in the upper and lower halves of the display, to serve as a reference for the midline. Several factors varied across trials: First, blob bounce positions were set at three locations before the midline, one at the midline, and three after the midline. The locations before the midline, which was indicated by the previously explained anchor blobs, were 20 pixels, 10 pixels, and five pixels before the midline. The locations after the midline were five pixels, 10 pixels, and 20 pixels after the middle of the screen which was indicated by the anchor blobs. Second, the blob size varied from what will be referred to as small, medium, and large throughout the experiment as indicated in Figure 7. The third variable that was manipulated was the sound offset position during the sounded trials, which will be discussed later.

The side at which the motion of the blobs started was randomized across trials. Participants were asked to press the 'CAPS LOCK' key on the keyboard if the ball bounced to the left of the midline and to press the 'ENTER' key on the keyboard if the ball bounced to the right of the midline regardless of which side the ball started. During some trials the blob bounced at the midline, where participants were instructed at the beginning of the experiment to make their best guess. The participants were told to respond as quickly and accurately as they could.

Table 1

Schematic of Experiment

Test Phase	Ball Size	Ball Bounce Position	Sound Offset	Start Side	Repetitions	Total Trials
	Pre-test					
Vision Test	3	7			2	42
Sound Test						10 (3 Silent)
Familiarization Phase	3	7 3	5 1 (after)	2 2	2 2	(420 + 36) =456 (30 randomly selected) **75 total**
	Test					
Testing Phase	3	7 3	5 1 (after)	2 2	2 2	(420 + 36) =456 (3 blocks) **456 total**

The vision-only (silent) trials were randomly mixed with the vision-sound trials (See Table 1). Vision-only trials were used to assess baseline performance in the absence of sound. Participants were required to press the key that corresponded to their perception of the bounce position as described previously. Each participant was presented with all three blob sizes during baseline trials.

The sounded trials required the same behavioral response as the silent trials. During the sounded trials, a brief auditory stimulus was presented at one of five temporal locations: synchronously, 33 ms before, 67 ms before, or 134 ms before the visual bounce. This is called the sound offset position. In addition to the synchronous and preceding sound offsets, some of the bounce positions were selected to have sound occur after the visual bounce. The bounce positions that had an “after” sound offset were considered the most ambiguous as determined from the results of the pilot study explained earlier. All preceding sound offset positions were presented for each ball size and ball bounce position as indicated in Table 1. The experiment was divided into three blocks to avoid fatigue in the participants.

The participants’ choice of where the blob bounced and latency were recorded to assess how quickly the participants identified the bounce position as being before or after the midline. Data from the familiarization trials was not used in the analyses.

CHAPTER 5

RESULTS

Data from 32 participants were not used. Participants were excluded for failure to respond, not following instructions, and/or lack of engagement in the experiment. These criteria were selected by analyzing their proportion of before or after responses and latency. Participants that did not respond to trials were excluded from the analyses. If responses were consistently in accordance with the starting position of the blob at the beginning of the trial or if latency was consistently and extremely negative, indicating responses at the beginning of the trial, the participant was identified as not following directions. In other words, if participant responses were always “before” and had large negative values, they were responding at the beginning of each trial to the side of the screen the blob first appeared and not to the bounce as they were instructed. Lack of engagement was subjectively identified by research assistants.

Two analyses were conducted to confirm that there were no statistical differences between analyses that included all participants and analyses that excluded participants based on the guidelines stated above. The first analysis included all participants, even those that violated the exclusion rules stated above. A second analysis was done following the exclusionary criteria and no differences in significance were found between the two analyses. This document contains the results from the second analysis for consistency across analyses and for an orderly presentation. Therefore, only data from 60 participants were analyzed for this experiment.

As previously mentioned, there were two pre-experimental tasks that participants completed, a vision test and an auditory test. The vision acuity task indicated that participants could identify the spatial location of the blobs when presented statically. Figure 5 shows the percentage of responses that the participants identified the blob as being to the left of the midline. The leftmost position had the most "left" responses (*M* = 99.72, *SE* = 0.28) and the rightmost location had no "left" responses. The middle location, which has the most ambiguous spatial attribute had responses that were slightly bias to indicate a "right of midline" decision (*M* = 38.33, *SE* = 3.33). All of the participants passed the auditory acuity test with 100% correct hits or rejections and no misses or false positives, and produced response latencies slightly slower than in the experimental conditions (*M* = 555.66, *SE* = 9.56), which will be explained later.

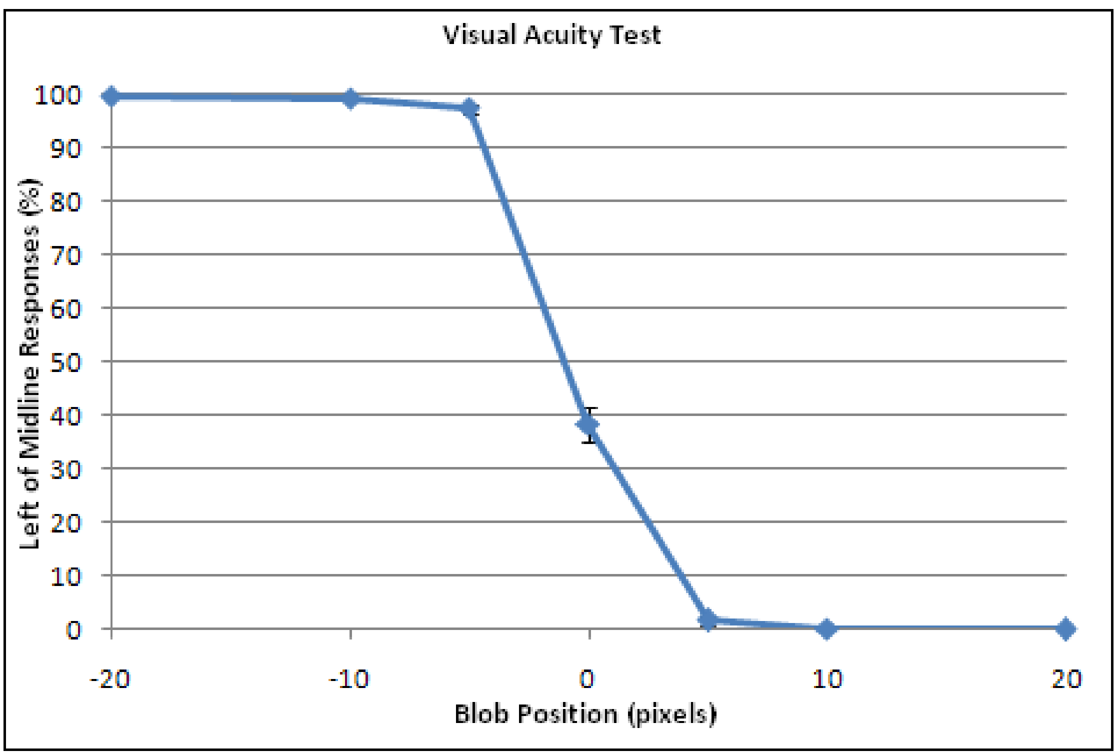

Figure 5. Results from Visual Acuity Test. The proportion of "left" responses is plotted across spatial location to indicate localization of visual stimuli.

The experiment was organized as a fully-crossed design, except for the 'after' sound offset condition, which was described earlier. Accordingly, a 3 x 5 x 7 within-subjects factorial ANOVA was used to analyze the data; Blob Size (small, medium, large), Sound Offset (silent, synchronous, -33ms, -67ms, -134ms), and Blob Bounce Position (-20 pixels, -10 pixels, -5 pixels, 0 pixels, 5, pixels, 10 pixels, 20 pixels). Two dependent variables were recorded: before or after responses and response latency to the bounce, recorded in milliseconds. Two separate ANOVAs were used to analyze each of the dependent measures. The first analysis examined the effect of Sound Offset, Blob Size, and Bounce Position on the proportion of before responses. The second, which will be described later, was used to analyze the same factors on response latency.

The first hypothesis stated that were would be a significantly higher proportion of before responses when sound was presented prior to the visual bounce than during silent trials. A main effect for Sound Offset on the proportion of before responses was found (F (4, 220) = 5.01, $p < .01$) (See Fig. 6). A Bonferroni post-hoc analysis showed that the Sound Offset of -134ms (M = 53.03, SE = 1.79) produced more before responses than the silent (M = 49.31, SD = 1.63) and synchronous (M = 50.20, SE = 1.60) sound positions. No difference in the proportion of before responses was found for the -33ms (M = 51.62, SE = 1.70) and -67ms (M = 51.22, SE = 1.79) sound offset positions compared to the other sound offset positions. Therefore, only one level of Sound Offset was found to be significantly different from the silent condition when analyzing the proportion of before responses. This supports the first hypothesis, but future manipulations will have to scrutinize this condition further.

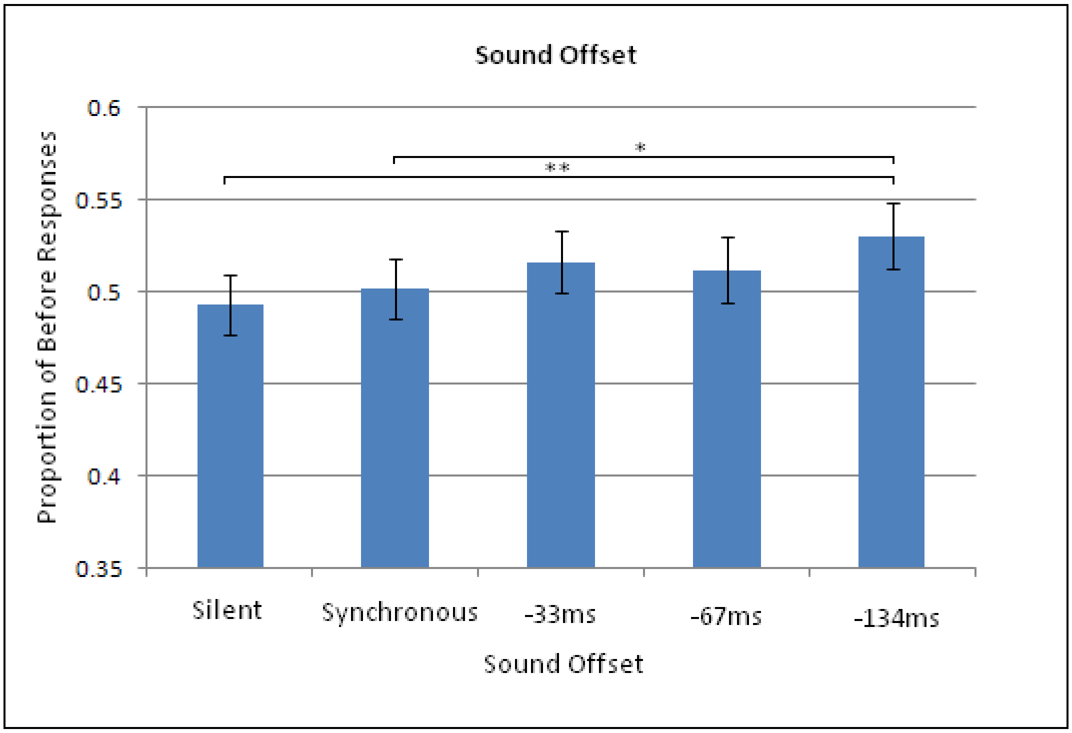

Figure 6. Post-hoc analyses of Sound Offset for proportion of before responses. A higher proportion of before responses for -134ms than silent or synchronously sounded trials is indicated.

An interaction of Blob Size and Bounce Position was proposed in hypothesis #2, which indicated a higher proportion of before responses for the small blob than the large blob at Bounce Positions occurring prior to and at the midline. The proportion of before responses for the medium blob was proposed to fall somewhere between the small and large blobs. An interaction of Blob Size and Bounce Position was found ($F(12, 660) = 59.567$, $p < .001$). Statistical differences for Blob Size at each Bounce Position are outlined in Table 2. The relationship expressed in hypothesis 2, 2a, and 2b was shown to be true (see Figure 10).

Simple effects tests for Blob Size across Bounce Positions were conducted to examine the interaction of Blob Size and Bounce Position (See Table 2). Hypothesis #2a was posited to investigate the effect of Bounce Position and Blob Size on the proportion of before responses in bounce locations that occur at and prior to the midline. These analyses are summarized in

Table 2. The results highlight the statistical differences in the proportion of before responses, at these specific locations, that were produced by the participants. In support of hypothesis #2a, these results confirm that there was a higher proportion of before responses produced for the small blob than the large blob at bounce positions before and at the midline. As shown in Table 2, with the exception of the midline location, the proportion of before responses for the medium blob fell between the proportion of before responses for the small and large blobs. This relationship supports hypothesis #2a at Bounce Positions of -10 and -5 pixels, and differences in the proportion of before responses were statistically significant at all hypothesized Bounce Positions (α = .007) (See Fig. 10).

Table 2

Simple effects tests for Blob Size at each Bounce Position

	Blob Size				
	Small	Medium	Large		
Bounce Position	% Before	% Before	% Before	F	p
-20	96.86 (0.86)^{A}	95.34 (1.02)^{A}	81.92 (2.53)^{B}	33.31	< .001
-10	94.77 (1.24)^{A}	89.83 (1.88)^{B}	62.03 (3.42)^{C}	72.45	< .001
-5	92.79 (1.70)^{A}	81.41 (2.62)^{B}	51.41 (3.60)^{C}	98.93	< .001
0	67.59 (3.01)^{A}	69.37 (3.46)^{A}	39.08 (3.67)^{B}	51.502	< .001
5	19.49 (2.35)^{A}	32.46 (3.02)^{B}	30.54 (3.38)^{C}	14.716	< .001
10	10.03 (1.59)^{A}	17.06 (2.54)^{B}	21.41 (2.71)^{B}	16.16	< .001
20	8.25 (1.51)^{A}	7.64 (1.46)^{A}	13.97 (2.36)^{B}	7.25	< .001

To investigate hypothesis #2b, another series of simple effects tests were required to analyze the effect of Bounce Position and Blob Size on the proportion of before responses for the Bounce Positions that occurred after the midline (See Table 2). This hypothesis stated that the relationship in the proportion of before responses after the midline would be the inverse of the relationship found prior to and at the midline. In other words, responses to the large blob would result in the highest proportion of before responses, the lowest proportion of before responses would be produced for the small blob, and the proportion of before responses for the medium blob would be in the middle. This relationship was shown to be true at the Bounce Positions 10 pixels, and there were statistically significant differences at all "after" Bounce Positions (α = .007) (See Fig.7).

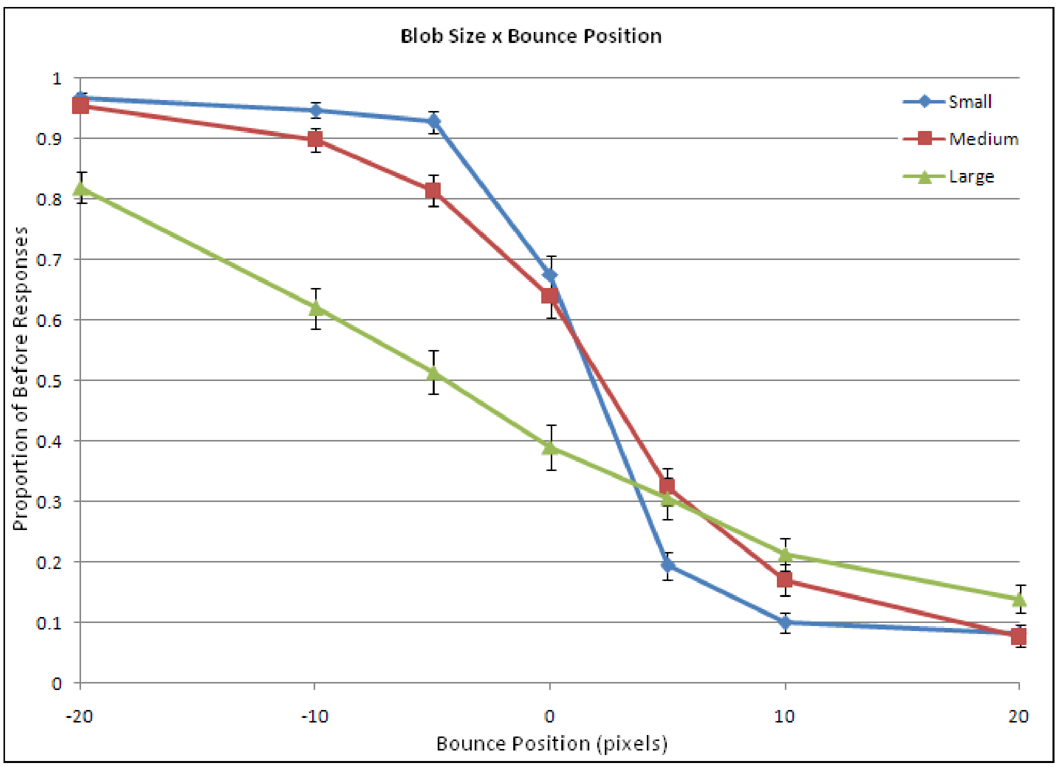

Figure 7. Interaction of Blob Size and Bounce Position on proportion of before responses. The different response patterns are shown when the levels of Blob Size are shown across Bounce Positions.

The third hypothesis pertained to the effect of Bounce Position on the proportion of before responses. Hypothesis #3 indicated that there would be a higher proportion of before responses for the bounce position located the closest to the start position than for the bounce position located the farthest from the start position. A main effect for Bounce Position on the proportion of before responses was found (F (6, 330) = 507.24, p < .001) (See Fig. 8). A Bonferroni post-hoc analysis for Bounce Position showed that the proportion of before responses at all bounce positions were significantly different from one another: -20 pixels (M = 91.12, SE = 1.21), -10 pixels (M = 81.88, SE = 1.71), -5 pixels (M = 74.96, SE = 2.14), 0 pixels (M = 56.25, SE = 2.96), 5 pixels (M = 27.60, SE = 2.61), 10 pixels (M = 16.2, SE= 2.06), and 20 pixels (M = 9.50, SE = 1.47) from midline.

As predicted in hypothesis #3a, the proportion of before responses followed a cubic function across bounce positions (F (1, 55) = 116.05, p < .001) (See Fig. 11). This relationship indicates that participants were able to identify bounce positions relatively easily at the extreme locations and had more difficulty in the middle positions, as indicated in this hypothesis.

No three-way interaction was found for the proportion of before responses (F (48, 2640) = 1.33, p > .05).

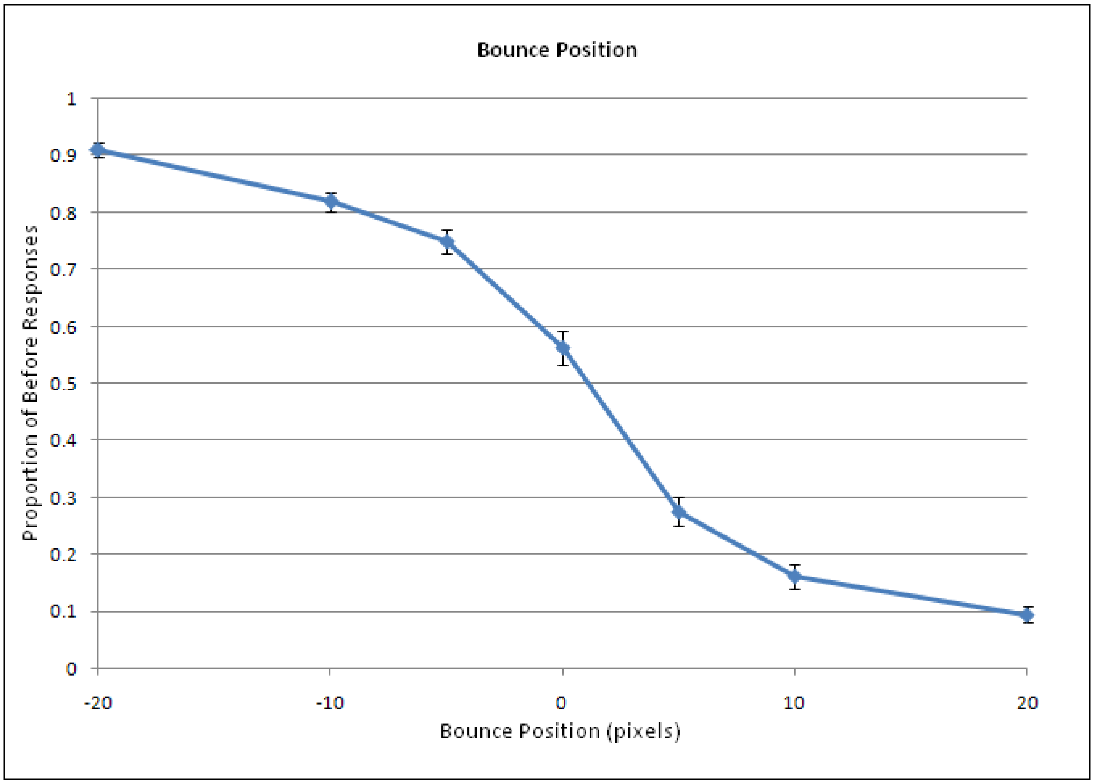

Figure 8. Main effect of Bounce Position on proportion of before responses. A sigmoidal trend was found for Bounce Position when analyzing the proportion of before responses.

A second 3 x 5 x 7 factorial ANOVA was done to investigate the effect of these experimental manipulations on the latency of responses: Blob Size (small, medium, large), Sound Offset (silent, synchronous, -33ms, -67ms, -134ms), and Blob Bounce Position (-20 pixels, -10 pixels, -5 pixels, 0 pixels, 5, pixels, 10 pixels, 20 pixels).

Hypothesis #4 indicated that were would be shorter latencies on trials where sound was presented prior to the visual bounce at Bounce Positions prior to and including the middle bounce position. A significant interaction of Sound Offset and Bounce Position was found ($F(24, 1320) = 2.419$, $p < .001$). In order to explore hypothesis #4, simple effects tests were used to assess the different effects of Sound Offset at each Bounce Position on latency. These analyses are summarized in Table 3 (α = .01). The results indicate that there is a facilitative effect of sound at bounce positions before and at the midline (See Fig. 9).

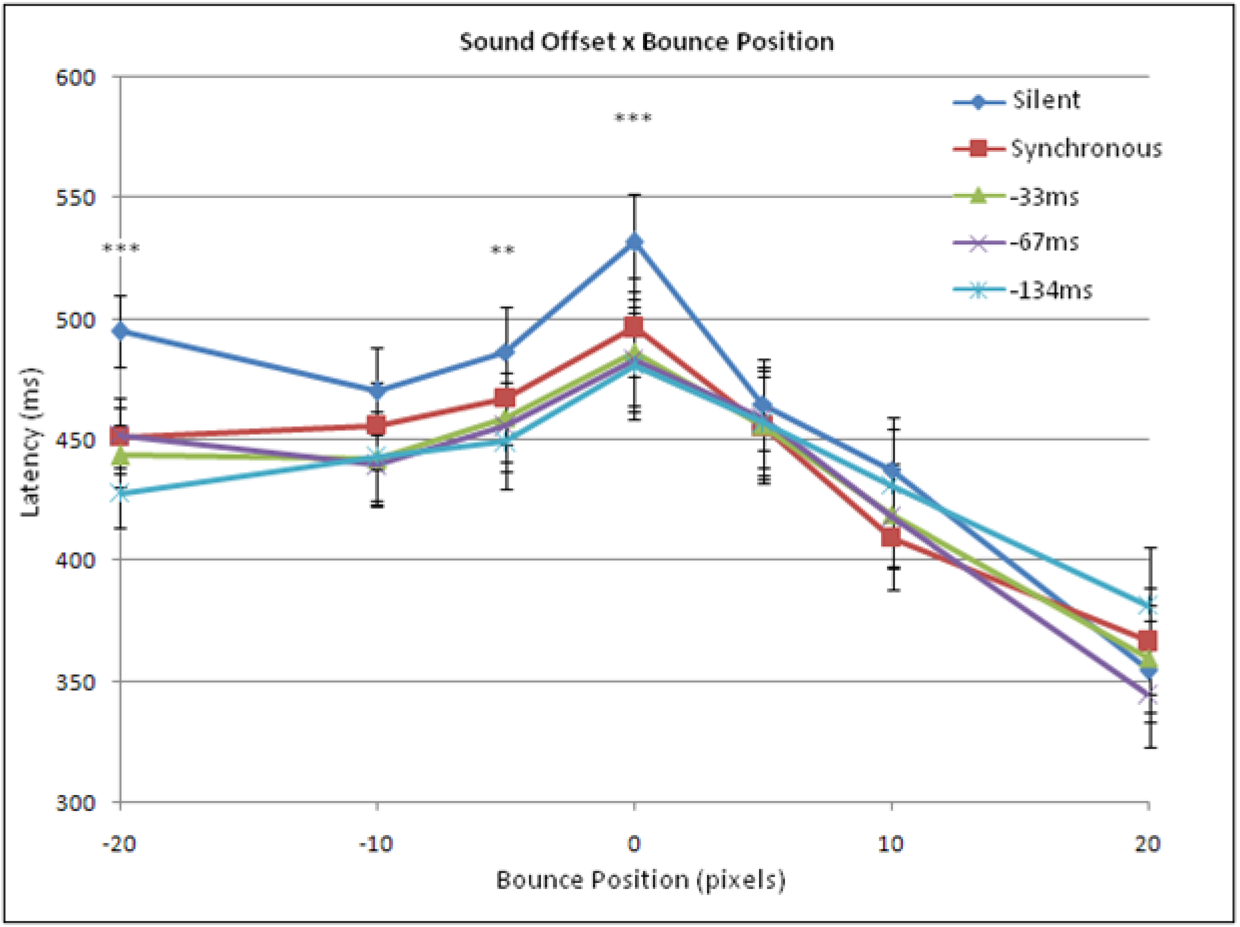

Figure 9. Interaction of Sound Offset and Bounce Position on latency. The pattern for latency remained constant across bounce positions prior to the midline. Latency was larger, however, for the silent trials, with the effect of sound disappearing at bounce positions that occurred after the midline.

The next series of simple effects tests investigated the differences in latency due to the presentation of sound at Bounce Positions occurring after the midline. Remember that hypothesis #4a stated that the facilitative effect of sound will be lost in Bounce Positions occurring after the midline. With the Bonferroni adjusted alpha level (α = .01), there were no significant effects on latency for Sound Offset at Blob Bounce Positions occurring after the midline (See Table 3). These analyses revealed that the facilitative properties of sound are lost at Bounce Positions occurring after the midline.

Table 3

Simple effects tests for Sound Offset at each Bounce Position

	Sound Offset						
Bounce Position	**Silent**	**Synchronous**	**-33ms**	**-67ms**	**-134ms**	**F**	**p**
-20	496.36 (14.74)^{A}	450.75 (13.11)^{B}	446.49 (14.04)^{B}	456.54 (15.13)^{B}	434.90 (15.22)^{B}	8.737	< .001
-10	470.18 (17.14)	460.61 (17.82)	443.24 (16.48)	445.97 (16.75)	444.24 (18.47)	2.32	> .05
-5	488.66 (17.88)^{A}	471.79 (18.73)^{B}	459.83 (18.10)^{B}	454.45 (18.34)^{B}	450.76 (19.20)^{B}	3.78	< .01
0	529.72 (19.58)^{A}	498.53 (20.75)^{B}	483.69 (21.41)^{B}	484.61 (20.96)^{B}	487.20 (22.29)^{B}	5.4	< .001
5	480.50 (20.23)	466.90 (24.03)	470.71 (21.23)	472.54 (21.34)	457.82 (24.75)	0.33	> .05
10	446.30 (21.53)	422.61 (21.61)	429.33 (21.06)	427.41 (20.91)	439.90 (23.23)	1.35	> .05
20	368.20 (21.43)	383.30 (22.32)	376.95 (21.50)	354.69 (21.50)	394.27 (23.63)	3.1	< .05

Hypotheses #5 refers to an interaction of Bounce Position and Blob Size. A factorial ANOVA revealed that there were indeed significant interactions for Bounce Position x Blob Size (F (12, 708) = 5.262, p < .001). This hypothesis stated that latency for the small and medium blobs would be larger in the middle bounce positions than for the large blob. Simple effects tests for Blob Size at the middle three Bounce Positions revealed that latency was in fact different for the three Blob Sizes at these Bounce Positions. Three separate ANOVAs were used to investigate the differences in latency at the middle Bounce Positions (-5 pixels, 0 pixels, and 5 pixels) for each Blob Size. An ANOVA for Bounce Position of -5 pixels indicated that there was no difference (F (2, 114) = 2.13, p >.05) in latencies for the small blob (M = 455.45, SE = 15.10), medium blob (M = 477.42, SE = 19.05), and large blob (M = 462.42, SE = 19.99) (See Table 6). At the midline, or Bounce Position of 0 pixels, an ANOVA showed a significant difference in latency for the different blob sizes (F (2, 118) = 12.756, p < .001). A Bonferroni post-hoc analysis indicated no difference for the small (*M* = 518.92, *SE* = 21.49) and medium (*M* = 512.19, *SE* = 19.75) blobs, but the large blob (*M* = 459.14, *SE* = 21.47) had a significantly smaller latency (F (2, 58) = 11.043, p < .001) (See Table 7). The same pattern as the midline location was found at Bounce Position of 5 pixels (F (2, 118) = 12.756, p < .001) (See Table 8). A Bonferroni post-hoc analysis indicated no difference for the small (*M* = 488.40, *SE* = 20.56) and medium (*M* = 486.60, *SE* = 22.87) blobs, but the large blob (*M* = 444.88, *SE* = 21.44) had a significantly smaller latency (p < .001). The relationship of latencies for each Blob Size across Bounce Position are shown in Figure 10.

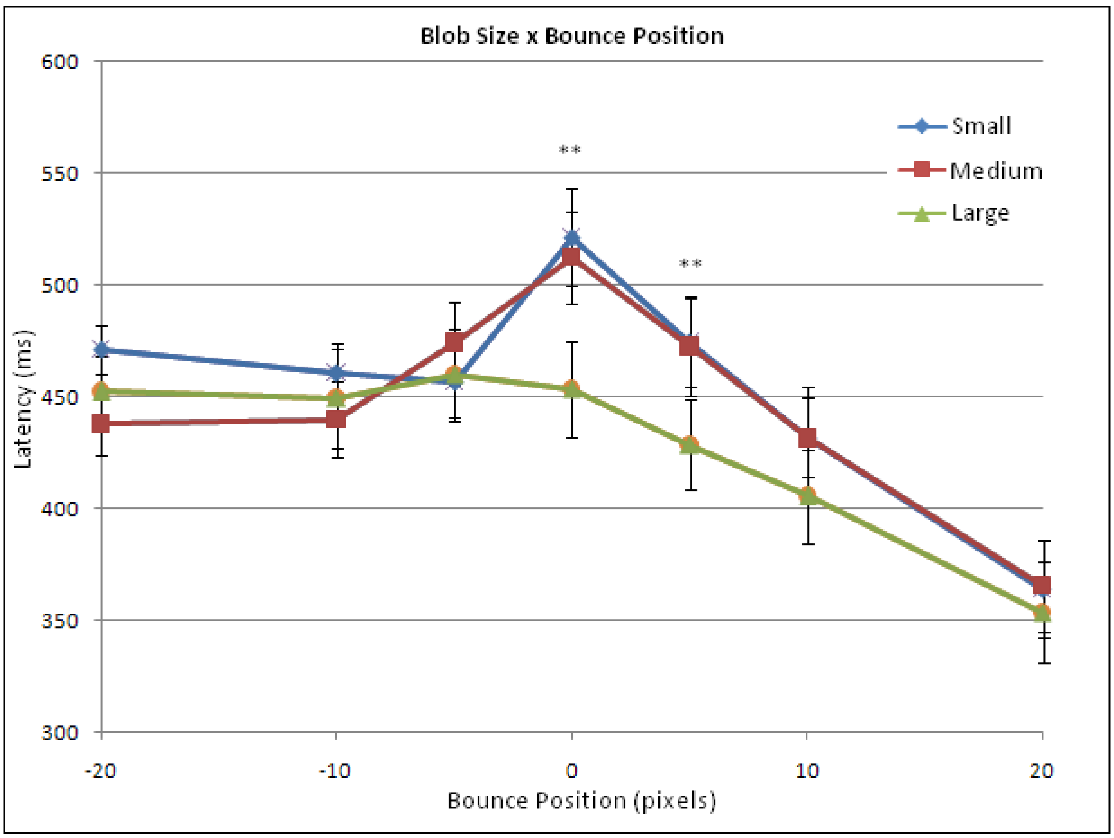

Figure 10. Interaction of Blob Size and Bounce Position on latency. Latency was larger in the middle bounce positions for the small and medium blobs. Latencies for all blobs were smaller in bounce positions that occurred after the midline.

The final hypothesis proposed that latency will be longer in trials where sound is presented after the visual bounce than in trials where the sound is presented prior to the visual bounce. As outlined in the previous chapter, only the middle three Bounce Positions had the "after" sound offset combined with them. This was due to the ambiguity of these Bounce Positions. This analysis, nonetheless, did reveal a statistical difference in latency for all Sound Offset positions (F (5, 270) = 6.082, p < .001). A Bonferroni post-hoc analysis, however, revealed no difference in latency for trials where sound was presented after the visual bounce (M = 476.26, SE = 18.64) and trials where sound was presented 33ms before (M = 464.07, SE = 19.09), 67ms before (M = 461.81, SE = 19.28), or 134ms before (M = 457.28, SE = 20.06) the visual bounce (See Fig. 11). Unfortunately, these results do not support the current hypothesis. Future manipulations to this experiment that stem from this hypothesis will be discussed in the next section.

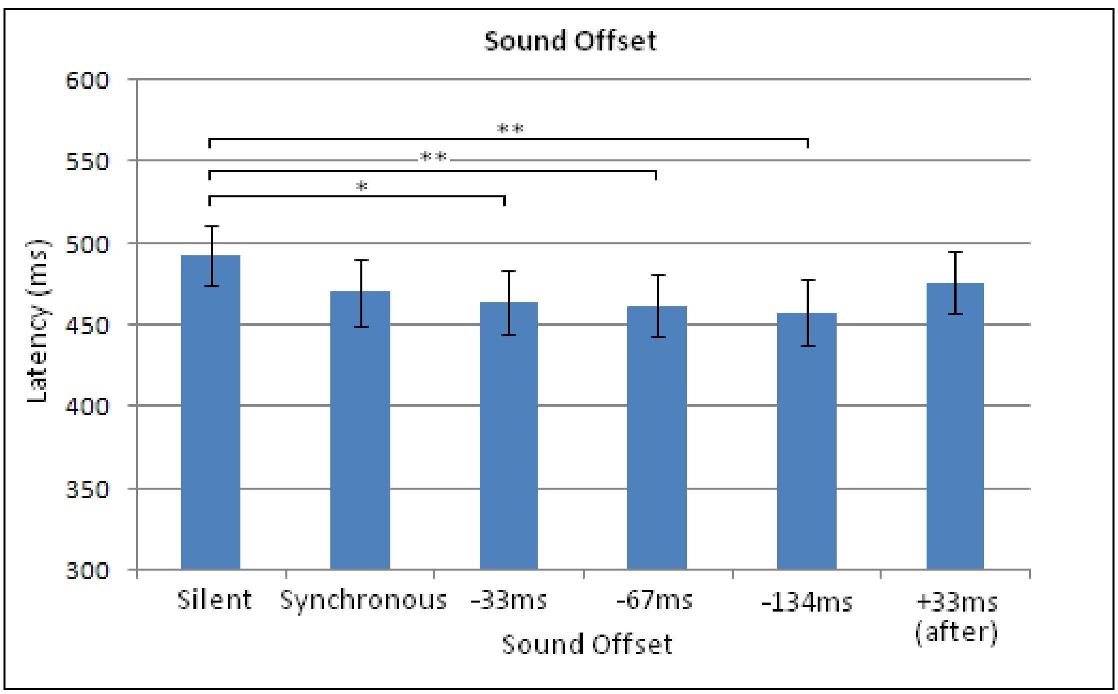

Figure 11. 'After' sound offset trials produce latencies similar to silent trials.

In summary, the proportion of before responses increased with the presentation of sound, the proportion of before responses decreased as blob size increased, and when the blob passed the midline, the proportion of before responses was significantly less. In addition, the proportion of before responses for the small and medium blobs was higher for bounce positions prior to the midline, whereas the proportion of before responses was higher for the large blob for bounce positions after the midline.

Hypotheses concerning latency were supported as well. When sound was presented during a trial, latency was shorter than when the trials were silent. Blob size had an effect on latency. Latency for the large blob was significantly smaller than latencies for the small and medium blobs. Also, the latencies in the middle bounce positions were shown to be longer than in the bounce positions farther away from the midline. In particular, latency at the middle blob bounce position was longer for the small and medium blobs but not the large blob. Additionally, as predicted, the facilitative effect of sound was shown to diminish in blob bounce positions that occurred after the midline.

CHAPTER 6

DISCUSSION

Several of the findings from the central study conducted by Heron et al. (2004) were replicated in the current study. The additional information obtained from recording latency during this study supported several of the posited hypotheses, as well. In this section, I will summarize and interpret each of the previously stated hypotheses in the order in which they were presented. Afterwards, I will explain how the results of the current experiment indicate a relationship between response choices and latency. Some ideas for future experimental manipulations have developed from this study. When relevant, these future manipulations will be addressed.

The first hypothesis was postulated to replicate the study by Heron et al. (2004). They found that with the presentation of sound, in trials with “uncertain” visual stimuli, there was an influence in participants’ percept of the visual bounce. In other words, when a brief click was presented prior to the bounce, participants saw the bounce of the fuzzier blobs occur earlier in time and space than when the actual bounce occurred. This was indicated by the proportion of before responses recorded during silent and sounded trials. The results of the current experiment were similar, though not identical, to their findings. Participant responses indicated that the bounce occurred before the midline more often in trials with the largest sound offset. There was not a significant difference in the proportion of before responses for the other sound offsets, which is not in accord with the central study. This may have occurred because in the study done by Heron et al., only a few participants were used and each participant had the bounce positions calibrated to match each of their thresholds for visual acuity (i.e., participants that could more accurately identify the location of bounce positions had the distances between bounce positions reduced until a specified criterion was reached). In the interest of the scope of this project, the bounce positions were derived from pilot study results, and were held constant throughout the study. In addition, we used a much larger sample size with fewer trials. In order to address this discrepancy, future experiments will include a phase that occurs prior to the testing phase that will match the visual stimuli to threshold for each participant to better replicate Heron et al. (2004).

The relationship of the proportion of before responses for blob size across bounce positions can be approached with the theme of this thesis, uncertainty. As indicated in the second hypothesis, the pattern of responses across bounce positions should vary as a function of how certain the participants are of the spatial location of the blob. This hypothesis was found to be true. In bounce locations before the midline, there was a higher proportion of before responses for the small blob, significantly less before responses for the large blob, and the proportion of before responses for the medium blob fell in between the other two. This response pattern can be explained by the spatial attributes of the stimuli. When the blob was small, or was of high spatial certainty for the participants, more before responses were produced verifying their certainty of the stimulus in space. In trials with the large blob, however, participants produced significantly less before responses for bounce positions occurring prior to the midline. This is indicative of spatial uncertainty, given that more after responses were produced for the same bounce positions as the small blob. This relationship is inversed for bounce positions occurring after the midline, which follows the same reasoning.

These results indicate that participants were more certain about the location of the bounce of the small blob and globally more uncertain about the location of the bounce for the large blob.

The third hypothesis stated that there would be a higher proportion of before responses at bounce positions that occur closer to the start position than at bounce positions that occur further away from the start position. This indicates that the proportion of before responses would decrease as the bounce position occurred further away from the start position. The hypothesis also suggests that at the midline bounce position, the proportion of before responses should be around 50%, indicating a high level of spatial uncertainty. Analyses revealed that there was a slight bias to the start position of the blob for each trial. This unwanted bias may be eliminated in later experiments by using a dynamic experimental environment, which will be discussed shortly. Another option would be to use a continuous bounce position variable rather than the discreet positions outlined in this experiment. Subjective equivalence would be met for each participant because all possible bounce positions would be presented and, therefore, eliminate the issue of trial “start-side” bias.

The cubic function that was postulated to explain the relationship of bounce position and the proportion of before responses was put forth to indicate that the relationship would not be a linear relationship. The bounce positions were selected from data collected in the pilot study. The bounce positions were selected based on three criteria: where the proportion of before/after responses approached asymptote, the middle position which should induce the most spatial uncertainty, and two locations before and two analogous positions after that were between the most uncertain middle position and the asymptotic outer positions. These pre-selected bounce positions resulted in a higher proportion of before responses at bounce positions before the midline, an area of uncertainty near the midline, and a low proportion of before responses at bounce positions after the midline. The area of uncertainty near the midline can be interpreted by examining the proportion of before responses. In the middle bounce position, the proportion of before responses approached 50%, with a slight bias towards the start side of the trial.

Participants watch the blob transverse the screen toward a predetermined point somewhere in the middle of the screen, and at that point, the blob reverses direction and returns to the start position. During the beginning of the trial, participants may be prepared to press the button that signifies a before response until the blob passes the midline, which is demarcated by anchor blobs. This “preparation” that participants experience may translate into anticipatory responses and as a result produce smaller latencies. The bias produced in this experiment due to start position may be eliminated. A manipulation that would address this issue is to use a dynamic environment that participants navigate in a video game setting (e.g., first-person shooter). If participants are navigating a dynamic environment, they would be able to approach each “trial” from any direction. Therefore, no start position would occur for a trial since the trials would be continuous and initiated from any number of angles. This would eliminate the start-side bias and may produce more ecological data for the interaction of auditory and visual stimuli than the current study.

The support for hypotheses concerning the proportion of before responses was promising in that the central study was replicated rather well. While reviewing Heron et al. (2004), however, the concept of reaction time or latency was encountered in other literature that evaluated crossmodal interactions. These studies presented one stimulus modality pretrial and another intratrial, whereas the current study used both stimuli intratrial. Therefore, participants were able to respond prior to the imperative stimulus. Since this type of response was possible, this study addressed the concept of latency rather than reaction time. To reiterate, the latency was recorded intra-trial and could have been produced by the participants at any time during a trial. This resulted in some latency values that were negative. These negative values are called anticipatory responses. These anticipatory responses could be investigated more thoroughly with different statistical techniques, such as probability density functions. Probability density functions allow researchers to more fully explore the behaviors of participants, either individually or as a group. This type of analysis may reveal that there are two separate behaviors being adopted by participants. Some participants may be exclusively using sound as a primary factor to respond, in ambiguous situations, while others respond to the visual cue as instructed. Some participants may produce behavioral patterns that reveal the use of both visual and auditory response patterns differentially across trials, whereas others may exclusively use one type of behavior to respond. Future analyses will adopt this method of analysis to better understand the behaviors adopted by the participants when responding to crossmodal stimuli.

The addition of latency recording to this study was motivated and investigated by several studies discussed earlier. This manipulation was posited to better examine the underlying processes involved during the trial as opposed to a decision made after the trial was over. By examining latency, assessments could be made to see if the addition of sound during the trials shifted the perception of the bounce position as posited by Heron et al. (2004) or if there was some other explanation. One such explanation may be that shortened latency, such as those found in this study, could be analogous to the increased number of before responses found in Heron et al. (2004).

As discussed in the first chapter, the fourth hypothesis was put forth to examine if the shorter latency, due to the presentation of sound, was a result of a shift in perception or due to some other underlying cognitive process. The presentation of sound was found to significantly reduce latency. This result brings to mind two possible conclusions. The shorter latencies were the result of an altered percept of the bounce position, as indicated by Heron et al. (2004), or there was a reduction of latency due to the additive properties of the stimuli acting on cortical areas, causing a facilitation of responses (Barutchu et al., 2003; Los et al., 1999; Rolke & Hofmann, 2007). Interestingly, we found shorter latencies when sound was presented synchronously with the bounce, which leads to the latter explanation to be of interest. The use of fMRI in future iterations of this line of experimentation should reveal any increased cortical activation due to these experimental manipulations.

Three levels of “certainty” among the blob sizes were verified by evaluating the proportion of before responses. Latency has been shown to be a good complementary manipulation with the proportion of before responses. Therefore, the relationship among blob sizes found in the proportion of before responses should map onto the relationship among blob sizes in regards to latency. Blob Size was found to influence latency, but this may lead to invalid assumptions. This result is from analyzing all data points, including both silent and sounded trials. If only the silent trials are analyzed, the main effect for blob size is no longer significant. This directs us to the conclusion that when sound is presented, participants rely on auditory cues for the fuzzier blobs which have low visual certainty. When visual certainty is high with the small blobs, however, participants rely solely on visual cues. This assumption agrees with the two separate behavioral patterns discussed earlier, using primarily sound during ambiguous situations or disregarding the auditory stimulus and using only visual cues. With this assumption in mind, we can address the next set of hypotheses which focus on bounce position. This hypothesis was validated when analyzing the interaction of sound offset and bounce position for latencies.

The interaction of bounce position and sound offset indicates a “switching” of system use during the trials. This interaction indicated that participants almost exclusively used their visual system when the bounce occurred after the midline. The facilitative effect of sound on latency is lost in bounce positions that occur after the midline. A simple explanation is that participants were noticing that the blob moved past the midline, therefore, the correct response had to be “after”. This can be further explained by the larger number of negative latencies that occur at bounce positions that occur after midline, indicating an anticipatory response.

The next interaction that was investigated was bounce position and blob size for latency. This interaction begins to reveal which perceptual system is used and what situations occasion the use of each system. Remember that participants were using their visual system when making responses in regards to visually salient objects (small blob) and visually salient locations (not occurring at the midline). The two behavioral response patterns that have been discussed, however, suggest that participants were using their auditory system to respond to cues when the visual stimulus was more ambiguous by either quality (i.e., fuzziness) or location. The interaction of bounce position and blob size illustrates this relationship. In the middle three bounce positions, the small and medium blob had larger latencies than the large blob. These results show that participants were disregarding the auditory cues and using primarily their visual system when the blobs' edges were distinguishable, but switching to auditory cues when the blobs' spatial information was ambiguous. The next series of experiments will be initially used to specifically investigate if this is the explanation for the irregularities found in the latency of responses for the large blob. For example, if probability density functions are used, as described earlier pertaining to anticipatory responses, they may reveal differential response patterns being used by participants for the trials with the large blob. If the PDFs are plotted across bounce positions and there are two "peaks" in density of responses, conclusions could be drawn that there are two separate and distinct patterns of responses occurring.

The final hypothesis that was investigated was whether or not a sound presented after the bounce would cause latency to be larger. This result was not statistically significant. There was, however, an addition to the "system-switch" concept that has been promoted in this section. In the graph that includes the "after" sound offset analysis, the latencies in the after condition and the silent condition are similar in means and standard errors. This may be because participants were already in the process of responding to what they believed were silent trials, therefore, sound had no effect on latency during these trials.

The current study has addressed several issues on audiovisual interactions in regards to the phenomenological experience of spatial certainty. When visual certainty is high, behavioral response patterns indicate that visual information may be used exclusively, to the extent that sounds accompanying the visual event may have no influence on spatial perception at all. Under visually ambiguous situations, behavioral patterns lead to the conclusion that responses may be based solely on auditory information, and as I have argued, vision may have little or no influence on spatial perception. The techniques people use to localize under these circumstances may vary between people and, depending on the difficulty, vary within the individual. Rather than an integration of the senses as illustrated in some theories, like MLE, a winner-takes-all situation may better explain the underlying process of audiovisual integration. The question of how people integrate information from multiple modalities in uncertain situations is beginning to unravel; perhaps the question is now "how uncertain must one be in order to use one sense over another?"

REFERENCES

Alais, D., Burr, D. (2004). The ventriloquist effect results from near-optimal bimodal integration. *Current Biology, 14*, 257-262.

Alsius, A., Navarra, J., Soto-Faraco, S. (2007). Attention to touch weakens audiovisual speech integration. *Experimental Brain Research, 183,* 399-404.

Barutchu, A., Crewther, S. G., Paolini, A. G., & Crewther, D. P. (2003). The effects of modality dominance and accuracy on motor reaction times to unimodal and bimodal stimuli [Abstract]. *Journal of Vision*, *3*(9):775, 775a.

Battaglia, P. W., Jacobs, R. A., Aslin, R. N. (2003). Bayesian integration of visual and auditory signals for spatial localization. *Optical Society of America, 20*(7), 1391-1397.

Calvert, G., Spence, C., Stein, B. (2004). The handbook of multisensory processes. Baskerville: Massachusetts Institute of Technology.

Christensen, C. (1983). Effects of color on aroma, flavor and texture judgments of foods. *Journal of Food Science, 48*(3), 787-790.

Dematte, M. L., Sanabria, D., Spence, C. (2007). Olfactory-tactile compatibility effects demonstrated using a variation of the Implicit Association Test. *Acta Psychologica, 124,* 332-343.

Erber, N. P. (1975). Auditory-visual perception of speech. *Journal of Speech and Hearing Disorders, 40*, 481-492.

Halligan, P. W., Marshall, J. C., Hunt, M., Wade, D. T. (1997). Somatosensory assessment: can seeing produce feeling? *Journal of Neurology, 244*(3), 199-203.

Heron, J., Whitaker, D., McGraw, P. V. (2004). Sensory uncertainty governs the extents of audio-visual interaction. *Vision Research, 44,* 2875-2884.

Kemp, S., Gilbert, A. (1997). Odor intensity and color lightness are correlated sensory dimensions. *American Journal of Psychology, 110*(1), 35-46.

Los, S. A., Knol, D. L., Boers, R. M. (2001). The foreperiod effect revisited: conditioning as a basis for nonspecific preparation. *Acta Psychologica, 106,* 121-145.

Mann, N. M. (2007). Taste, smell, and flavor: when senses go awry. *Cortland Forum, 44,* 41-43.

Meyer, G. F., Wuerger, S. M. (2001). Crossmodal integration of auditory and visual motion signals. *Neuroreport, 12*(11), 2557-2660.

Mozolic, J. L., Hugenschmidt, C. E., Peiffer, A. M., Laurienti, P. J. (2007). Modality specific selective attention attenuates multisensory integration. *Experimental Brain Research, 184*, 39-52.

Pouget, A., Deneve, S., Duhamel, J. (2002). A computational perspective on the neural basis of multisensory spatial representations. *Neuroscience, 3*, 741-748.

Rolke, B., Hofmann, P. (2007). Temporal uncertainty degrades perceptual processing. *Psychonomic Bulletin & Review, 14*(3), 522-526.

Sanabria, D., Luplanez, J., Spence, C. (2006). Auditory motion affects visual motion perception in a speeded discrimination task. *Experimental Brain Research, 178*, 415-421.

Sekuler, R., Sekuler, A. B., Lau, R. (1997). Sound alters visual motion perception. *Science, 385*, 308.

Shams, L., Kamitani, Y., Shimojo, S. (2001). Visual illusion induced by sound. *Cognitive Brain Research, 14*, 147-152.

Spence, C., & Driver, J. (1999). A new approach to the design of multimodal warning signals. In D. Harris (Ed.), *Engineering psychology and cognitive ergonomics: Vol. 4. Job design, product design and human-computer interaction* (pp. 455-461). Hampshire, England: Ashgate.

Zhou, F., Wong, V., Sekuler, R. (2007). Multi-sensory integration of spatio-temporal segmentation cues: one plus one does not always equal two. *Experimental Brain Research, 180*, 641-654.

APPENDIX A

Table 4

Mean difference scores for Bounce Position at -20 pixels

Bounce			Small^{A}					Medium^{B}					Large^{AB}				
Position = -20			silent^{A}	synchronous^{B}	-33^{B}	-67^{B}	-134^{B}	silent	synchronous	-33	-67	-134	silent	synchronous	-33	-67	-134
		Mean Latency	**521.593**	**449.981**	**452.861**	**475.15**	**466.461**	**477.913**	**439.261**	**431.824**	**434.346**	**411.376**	**494.228**	**470.003**	**450.028**	**461.739**	**424.434**
Small	silent	**521.593**	0	-71.612*	-68.732*	-46.443*	-55.132*	-43.68	-82.332	-89.769	-87.247	-110.217	-27.365	-51.59	-71.565	-59.854	-97.159
	sync	**449.981**		0	2.88	25.169	27.932	27.932	-10.72	-18.157	-15.635	-38.605	44.247	20.022	0.047	11.758	-25.547
	-33	**452.861**			0	22.289	13.6	25.052	-13.6	-21.037	-18.515	-41.485	41.367	17.142	-2.833	8.878	-28.427
	-67	**475.15**				0	-8.689	2.763	-35.889	-43.326	-40.804	-63.774	19.078	-5.147	-25.122	-13.411	-50.716
	-134	**466.461**					0	11.452	-27.2	-34.637	-32.115	-55.085	27.767	3.542	-16.433	-4.722	-42.027
Medium	silent	**477.913**						0	-38.652	-46.089*	-43.567*	-66.537*	16.315	-7.91	-27.885	-16.174	-53.479
	sync	**439.261**							0	-7.437	-4.915	-27.885	54.967	30.742	10.767	22.478	-14.827
	-33	**431.824**								0	2.522	-20.448	62.404	38.179	18.204	29.915	-7.39
	-67	**434.346**									0	-22.97	59.882	35.657	15.682	27.393	-9.912
	-134	**411.376**										0	82.852	58.627	38.652	50.363	13.058
Large	silent	**494.228**											0	-24.225	-44.2	-32.489	-69.794
	sync	**470.003**												0	-19.975	-8.264	-45.569
	-33	**450.028**													0	11.711	-25.594
	-67	**461.739**														0	-37.305
	-134	**424.434**															0

Table 5

Mean difference scores for Bounce Position at -10 pixels

Bounce			Small^{A}					Medium^{B}					Large^{AB}				
Position = -10			silent^{A}	synchronous^{AB}	-33^{B}	-67^{AB}	-134^{AB}	silent	synchronous	-33	-67	-134	silent	synchronous	-33	-67	-134
		Mean Latency	**504.711**	**477.629**	**443.959**	**457.7**	**439.072**	**442.283**	**453.664**	**439.049**	**443.299**	**437.608**	**479.565**	**462.967**	**451.869**	**453.145**	**459.816**
Small	silent	**504.711**	0	-27.082	-60.752*	-47.01*	-65.639*	-62.428	-51.047	-65.662	-61.412	-67.103	-25.146	-41.744	-52.842	-51.566	-44.895
	sync	**477.629**		0	-33.67	-19.928	-35.346	-35.346	-23.965	-38.58	-34.33	-40.021	1.936	-14.662	-25.76	-24.484	-17.813
	-33	**443.959**			0	13.742	-4.887	-1.676	9.705	-4.91	-0.66	-6.351	35.606	19.008	7.91	9.186	15.857
	-67	**457.701**				0	-18.629	-15.418	-4.037	-18.652	-14.402	-20.093	21.864	5.266	-5.832	-4.556	2.115
	-134	**439.072**					0	3.211	14.592	-0.023	4.227	-1.464	40.493	23.895	12.797	14.073	20.744
Medium	silent	**442.283**						0	11.381	-3.234	1.016	-4.675	37.282	20.684	9.586	10.862	17.533
	sync	**453.664**							0	-14.615	-10.365	-16.056	25.901	9.303	-1.795	-0.519	6.152
	-33	**439.049**								0	4.25	-1.441	40.516	23.918	12.82	14.096	20.767
	-67	**443.299**									0	-5.691	36.266	19.668	8.57	9.846	16.517
	-134	**437.608**										0	41.957	25.359	14.261	15.537	22.208
Large	silent	**479.565**											0	-16.598	-27.696	-26.42	-19.749
	sync	**462.967**												0	-11.098	-9.822	-3.151
	-33	**451.869**													0	1.276	7.947
	-67	**453.145**														0	6.671
	-134	**459.816**															0

Table 6

Mean difference scores for Bounce Position at -5 pixels

Bounce			Small^{A}					Medium^{A}					Large^{A}				
Position = -5			silent^{A}	synchronous^{AB}	-33^{AB}	-67^{AB}	-134^{B}	silent	synchronous	-33	-67	-134	silent	synchronous	-33	-67	-134
		Mean Latency	491.276	471.089	458.079	436.03	445.919	503.625	476.96	472.879	471.491	472.086	488.774	469.565	459.888	479.164	453.097
Small	silent	491.276	0	-20.187	-33.197	-55.25	-45.357 *	12.349	-14.316	-18.397	-19.785	-19.19	-2.502	-21.711	-31.388	-12.112	-38.179
	sync	471.089		0	-13.01	-35.063	32.536	32.536	5.871	1.79	0.402	0.997	17.685	-1.524	-11.201	8.075	-17.992
	-33	458.079			0	-22.053	-12.16	45.546	18.881	14.8	13.412	14.007	30.695	11.486	1.809	21.085	-4.982
	-67	436.026				0	9.893	67.599	40.934	36.853	35.465	36.06	52.748	33.539	23.862	43.138	17.071
	-134	445.919					0	57.706	31.041	26.96	25.572	26.167	42.855	23.646	13.969	33.245	7.178
Medium	silent	503.625						0	-26.665	-30.746	-32.134	-31.539	-14.851	-34.06	-43.737	-24.461	-50.528
	sync	476.96							0	-4.081	-5.469	-4.874	11.814	-7.395	-17.072	2.204	-23.863
	-33	472.879								0	-1.388	-0.793	15.895	-3.314	-12.991	6.285	-19.782
	-67	471.491									0	0.595	17.283	-1.926	-11.603	7.673	-18.394
	-134	472.086										0	16.688	-2.521	-12.198	7.078	-18.989
Large	silent	488.774											0	-19.209	-28.886	-9.61	-35.677
	sync	469.565												0	-9.677	9.599	-16.468
	-33	459.888													0	19.276	-6.791
	-67	479.164														0	-26.067
	-134	453.097															0

Table 7

Mean difference scores for Bounce Position at 0 pixels

Bounce			Small^{A}					Medium^{A}					Large^{B}				
Position = 0			silent^{A}	synchronous^{A}	-33^{B}	-67^{B}	-134^{AB}	silent	synchronous	-33	-67	-134	silent	synchronous	-33	-67	-134
		Mean Latency	542.206	529.521	497.97	525.68	519.893	563.161	515.431	524.214	525.678	498.738	488.366	478.834	442.757	452.389	470.475
Small	silent	542.206	0	-12.685	-44.236	-16.528	-22.313	20.955	-26.775	-17.992	-16.528	-43.468	-53.84	-63.372	-99.449	-89.817	-71.731
	sync	529.521		0	-31.551	-3.843	33.64	33.64	-14.09	-5.307	-3.843	-30.783	-41.155	-50.687	-86.764	-77.132	-59.046
	-33	497.97			0	27.708	21.923	65.191	17.461	26.244	27.708	0.768	-9.604	-19.136	-55.213	-45.581	-27.495
	-67	525.678				0	-5.785	37.483	-10.247	-1.464	0	-26.94	-37.312	-46.844	-82.921	-73.289	-55.203
	-134	519.893					0	43.268	-4.462	4.321	5.785	-21.155	-31.527	-41.059	-77.136	-67.504	-49.418
Medium	silent	563.161						0	-47.73	-38.947	-37.483	-64.423*	-74.795	-84.327	-120.4	-110.77	-92.686
	sync	515.431							0	8.783	10.247	-16.693	-27.065	-36.597	-72.674	-63.042	-44.956
	-33	524.214								0	1.464	-25.476	-35.848	-45.38	-81.457	-71.825	-53.739
	-67	525.678									0	-26.94	-37.312	-46.844	-82.921	-73.289	-55.203
	-134	498.738										0	-10.372	-19.904	-55.981	-46.349	-28.263
Large	silent	488.366											0	-9.532	-45.609	-35.977	-17.891
	sync	478.834												0	-36.077	-26.445	-8.359
	-33	442.757													0	9.632	27.718
	-67	452.389														0	18.086
	-134	470.475															0

Table 8

Mean difference scores for Bounce Position at 5 pixels

Bounce			Small[A]					Medium[A]					Large[B]				
Position = 5			silent[A]	synchronous[A]	-33[A]	-67[A]	-134[A]	silent	synchronous	-33	-67	-134	silent	synchronous	-33	-67	-134
		Mean Latency	**464.879**	**489.151**	**480.675**	**490.45**	**507.07**	**516.115**	**473.946**	**488.278**	**490.45**	**473.19**	**456.639**	**434.539**	**439.521**	**449.768**	**441.032**
Small	silent	**464.879**	0	24.272	15.796	25.571	42.191	51.236	9.067	23.399	25.571	8.311	-8.24	-30.34	-25.358	-15.111	-23.847
	sync	**489.151**		0	-8.476	1.299	26.964	26.964	-15.205	-0.873	1.299	-15.961	-32.512	-54.612	-49.63	-39.383	-48.119
	-33	**480.675**			0	9.775	26.395	35.44	-6.729	7.603	9.775	-7.485	-24.036	-46.136	-41.154	-30.907	-39.643
	-67	**490.45**				0	16.62	25.665	-16.504	-2.172	0	-17.26	-33.811	-55.911	-50.929	-40.682	-49.418
	-134	**507.07**					0	9.045	-33.124	-18.792	-16.62	-33.88	-50.431	-72.531	-67.549	-57.302	-66.038
Medium	silent	**516.115**						0	-42.169	-27.837	-25.665	-42.925	-59.476	-81.576	-76.594	-66.347	-75.083
	sync	**473.946**							0	14.332	16.504	-0.756	-17.307	-39.407	-34.425	-24.178	-32.914
	-33	**488.278**								0	2.172	-15.088	-31.639	-53.739	-48.757	-38.51	-47.246
	-67	**490.45**									0	-17.26	-33.811	-55.911	-50.929	-40.682	-49.418
	-134	**473.19**										0	-16.551	-38.651	-33.669	-23.422	-32.158
Large	silent	**456.639**											0	-22.1	-17.118	-6.871	-15.607
	sync	**434.539**												0	4.982	15.229	6.493
	-33	**439.521**													0	10.247	1.511
	-67	**449.768**														0	-8.736
	-134	**441.032**															0

Table 9

Mean difference scores for Bounce Position at 10 pixels

Bounce			Small[A]					Medium[A]					Large[A]				
Position = 10			silent[A]	synchronous[A]	-33[A]	-67[A]	-134[A]	silent	synchronous	-33	-67	-134	silent	synchronous	-33	-67	-134
		Mean Latency	**441.575**	**415.296**	**434.373**	**456.12**	**461.314**	**450.24**	**453.617**	**434.373**	**427.857**	**443.2**	**452.814**	**408.567**	**426.794**	**405.119**	**420.774**
Small	silent	**441.575**	0	-26.279	-7.202	14.545	19.739	8.665	12.042	-7.202	-13.718	1.625	11.239	-33.008	-14.781	-36.456	-20.801
	sync	**415.296**		0	19.077	40.824	34.944	34.944	38.321	19.077	12.561	27.904	37.518	-6.729	11.498	-10.177	5.478
	-33	**434.373**			0	21.747	26.941	15.867	19.244	0	-6.516	8.827	18.441	-25.806	-7.579	-29.254	-13.599
	-67	**456.12**				0	5.194	-5.88	-2.503	-21.747	-28.263	-12.92	-3.306	-47.553	-29.326	-51.001	-35.346
	-134	**461.314**					0	-11.074	-7.697	-26.941	-33.457	-18.114	-8.5	-52.747	-34.52	-56.195	-40.54
Medium	silent	**450.24**						0	3.377	-15.867	-22.383	-7.04	2.574	-41.673	-23.446	-45.121	-29.466
	sync	**453.617**							0	-19.244	-25.76	-10.417	-0.803	-45.05	-26.823	-48.498	-32.843
	-33	**434.373**								0	-6.516	8.827	18.441	-25.806	-7.579	-29.254	-13.599
	-67	**427.857**									0	15.343	24.957	-19.29	-1.063	-22.738	-7.083
	-134	**443.2**										0	9.614	-34.633	-16.406	-38.081	-22.426
Large	silent	**452.814**											0	-44.247	-26.02	-47.695	-32.04
	sync	**408.567**												0	18.227	-3.448	12.207
	-33	**426.794**													0	-21.675	-6.02
	-67	**405.119**														0	15.655
	-134	**420.774**															0

Table 10

Mean difference scores for Bounce Position at 20 pixels

Bounce			Small[A]					Medium[A]					Large[A]				
Position = 20			silent[A]	synchronous[A]	-33[A]	-67[AB]	-134[B]	silent	synchronous	-33	-67	-134	silent	synchronous	-33	-67	-134
		Mean Latency	377.92	354.332	368.853	373.1	421.293	361.061	403.774	380.729	350.359	400.822	365.618	391.803	381.272	340.567	360.707
Small	silent	377.92	0	-23.588	-9.067	-4.817	43.373	-16.859	25.854	2.809	-27.561	22.902	-12.302	13.883	3.352	-37.353	-17.213
	sync	354.332		0	14.521	18.771	66.961*	6.729	49.442	26.397	-3.973	46.49	11.286	37.471	26.94	-13.765	6.375
	-33	368.853			0	4.25	52.44	-7.792	34.921	11.876	-18.494	31.969	-3.235	22.95	12.419	-28.286	-8.146
	-67	373.103				0	48.19	-12.042	30.671	7.626	-22.744	27.719	-7.485	18.7	8.169	-32.536	-12.396
	-134	421.293					0	-60.232	-17.519	-40.564	-70.934	-20.471	-55.675	-29.49	-40.021	-80.726	-60.586
Medium	silent	361.061						0	42.713	19.668	-10.702	39.761	4.557	30.742	20.211	-20.494	-0.354
	sync	403.774							0	-23.045	-53.415	-2.952	-38.156	-11.971	-22.502	-63.207	-43.067
	-33	380.729								0	-30.37	20.093	-15.111	11.074	0.543	-40.162	-20.022
	-67	350.359									0	50.463	15.259	41.444	30.913	-9.792	10.348
	-134	400.822										0	-35.204	-9.019	-19.55	-60.255	-40.115
Large	silent	365.618											0	26.185	15.654	-25.051	-4.911
	sync	391.803												0	-10.531	-51.236	-31.096
	-33	381.272													0	-40.705	-20.565
	-67	340.567														0	20.14
	-134	360.707															0

VITA

Graduate School
Southern Illinois University

Joseph W. Geeseman Date of Birth: July 18, 1981

1101 East Grand Ave. #Z-3, Carbondale, Illinois 62901

jgoose@siu.edu

Southern Illinois University Carbondale
Bachelor of Arts, Psychology, December 2005

Special Honors and Awards:
Arthur Menendez Vision Research Award, 2009

Thesis Title:
The influence of auditory cues on visual spatial perception

Major Professor: Matthew J. Schlesinger